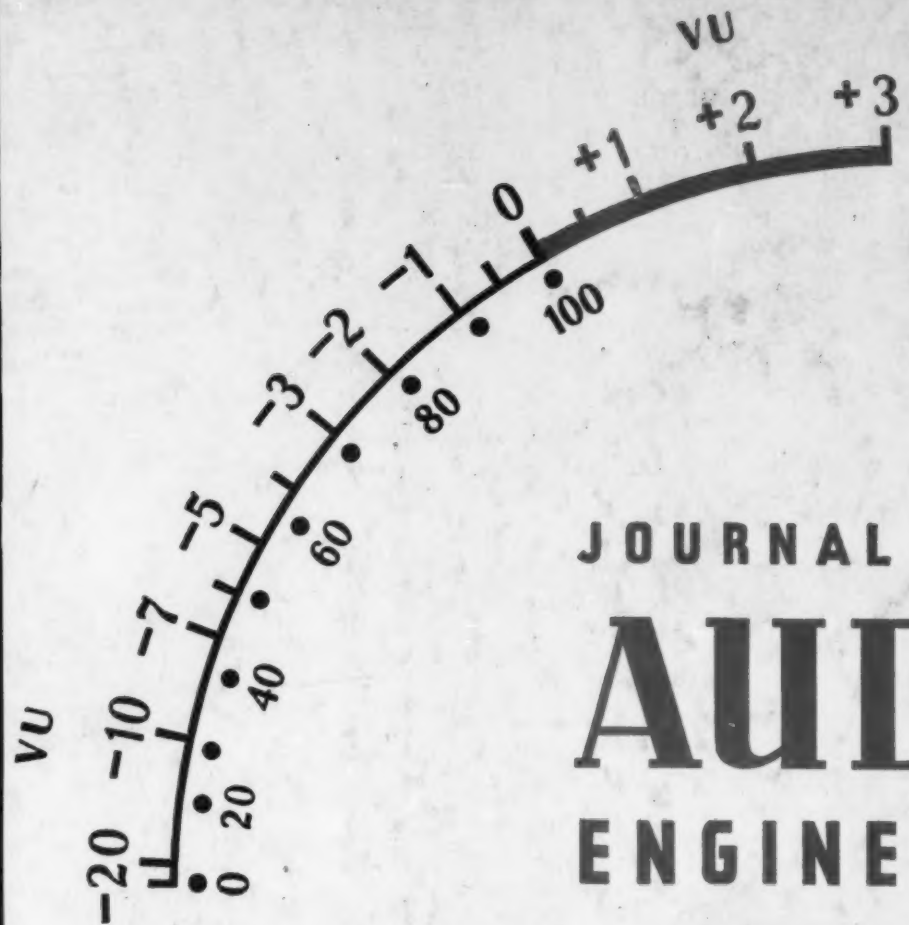

JOURNAL OF THE AUDIO ENGINEERING SOCIETY

COMING

October — The Seventh Annual Audio Engineering Society Convention and Audio Fair

VOLUME 3 NUMBER 1 JANUARY 1955

2343-603-1

Convention Program Committee Urges Prospective Authors To Submit Author's Forms and Manuscripts Immediately

PROMPT ACTION WILL INSURE MAXIMUM PUBLICITY, LOCALLY AND NATIONALLY, FOR PAPERS AND AUTHORS AND SPEED PUBLICATION OF THE *JOURNAL*

The Seventh Annual Convention of the Audio Engineering Society will take place October 12-15 inclusive, 1955, at the Hotel New Yorker in New York City. The Audio Fair (Audiorama), incidentally, will run October 13-16 inclusive.

The main theme of the AES Convention will be: *How to make equipment practical*—i.e., *how best to enable audio equipment—and related equipment of all kinds—to carry out its intended purpose effectively.*

PAPERS TO COVER WIDE RANGE OF AUDIO SUBJECTS

Tentatively scheduled are papers on amplifier testing; distortion measurements; transistors in audio; the synthesis and analysis of speech and music; psychoacoustics; correlation between sight and sound; broadcast and recording studio design, installation, maintenance and operation; and problems in the design and installation of public address and other audio systems.

HI-FI TALKS FOR PUBLIC PLANNED

In addition to the engineering meetings, a number of sessions on high fidelity, designed specifically for the consumer, are planned. The theme of these sessions will be: *How to select and build components for audio systems and how to tie systems together.* This group of talks will be couched in popular terms.

Tentatively scheduled, too, is a panel or symposium on the controversial matter of criteria in record reviewing.

*

THE GOALS: CUT TIME LAG, GET MAXIMUM PUBLICITY

One of the goals of the Audio Engineering Society is to cut down the time lag between presentation of papers and appearance in the JOURNAL of papers accepted for publication.

Another goal of the AES is to secure maximum national and local publicity—in regular newspapers, in scientific and technical journals and in the trade press—for the AES Convention, for the papers to be presented and for their authors personally.

HELP SELF BY HELPING AES

In order to help the AES achieve these goals in connection with the coming October Convention, persons desiring to submit papers on audio or on any related, pertinent subjects, will please do the following:

(1) Communicate your intention to submit a paper (along with an abstract of your proposed paper) as quickly as possible to the Chairman of the Convention Program Committee.

Several copies of the Audio Engineering Society's Author's Form will be mailed to you immediately.

(2) Prepare your manuscript—even if it is only a preliminary version—as quickly as possible.

WHERE TO SEND THE CARBON

The first carbon—a good, clean carbon—should be mailed to the Chairman, Program Convention Committee. *Purpose*: To permit final scheduling of your paper and to allow publicity work to begin.

WHERE TO SEND THE ORIGINAL

The *original* of the manuscript—i.e., the *ribbon* copy (plus all photographs, diagrams, charts, graphs and other illustrative materials)—should be mailed to the Managing Editor of the JOURNAL OF THE AES. *Purpose*: To enable the Managing Editor to start the manuscript moving through the regular reviewing and preparation channels without delay, in *advance* of the Convention proper.

*

R. H. Ranger, Convention Program Chairman, and Julius Postal, Managing Editor of the JOURNAL OF THE AES, may be addressed care of the

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*

A number of suggestions for prospective authors will be found on the inside rear cover page of the JOURNAL.

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Good luck!

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Journal of the
AUDIO ENGINEERING SOCIETY

VOLUME 3 NUMBER 1

JANUARY 1955

On Stylus Wear and Surface Noise in Phonograph Playback Systems*

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A theory of rubbing wear found useful in other fields predicts that the volume of stylus (or record) material worn away is proportional to the area of "real" contact between the stylus and the groove wall. In order to evaluate the influence of system parameters on the real-contact area, the elastic-plastic regime prevailing under the stylus is first analyzed in detail. The enhancement of the effective yield strength of record materials by the so-called size effect is found to have a dominant influence on the stylus-groove contact. Application of these results to the wear problem leads to the prediction that stylus life could be extended by as much as one or two orders of magnitude if the conventional dynamic loading of the stylus contact were lowered enough to insure that no plastic yielding could ever occur even at the peak acceleration demand for either vertical or lateral motion. Avoidance of plastic yielding is also shown to remove an important component of surface noise originating in the microscale intermittency of plastic flow.

INTRODUCTION

SUBSTANTIAL progress has been made during the last ten years in almost every branch of phonograph technology except that relating to the rate at which needles and records wear out. Unfortunately for the consumer, the life expectancy of these two components of the playback process appears to have done no better than to hold its own—and perhaps not even that—during this decade.

These speculations about the fundamental nature of the wear process represent an attempt to devise a plausible explanation for three observations made by J. A. Pierce and me just shortly before the outbreak of World War II, when we were using an experimental lightweight dynamic pickup in our studies of tracing distortion. Throughout this period of prewar experimentation we were impressed by the fact that our records, even lacquers, did not seem to wear out, and we never observed any traces of wear on our sapphire styli. For example, we played one particular shellac pressing more than 700 times with no detectable increase in surface noise; also, no stylus in our experimental pickups ever developed a "flat" large enough to be detected under casual microscopic examination. As for the surface noise itself,

* Presented under the title, "Speculations on the Cause and Prevention of Needle Wear and Surface Noise in the Phonograph Playback Process," at the Sixth Annual Convention of the Audio Engineering Society, New York, October 14–16, 1954.

† Rumford Professor of Physics and Gordon McKay Professor of Applied Physics, Division of Applied Science, Harvard University.

this always appeared to be substantially lower than we had any right to expect in view of the passband of our playback system. We never ventured to claim publicly this apparent reduction of surface noise because we were not able then to offer any convincing explanation for it, but our belief in its validity was sustained by the occasional informal testimony of others who had also experimented with very lightweight reproducers and who had made similar observations.

The accurate measurement of needle wear rates is very difficult, and I do not know of any systematic quantitative study of this problem prior to that reported by Bauer[1] in 1951. One consequence of this lacuna was that a long time elapsed before Pierce and I realized that the wear rates we had observed were not only low but were anomalously low by as much as one to three orders of magnitude! To be sure, the mechanical constants of our 1940 pickup[2] did differ from those of the conventional pickups now available, and in the right directions to account for a somewhat lower wear rate. For example, if it be assumed for the purpose of this discussion that "conventional" loading means a bearing weight of 15 grams on a 3-mil radius stylus (or 5 grams for a 1-mil stylus), then the 5 to 7 grams that we used with a 2.85-mil stylus could, according to Bauer's analysis, account for something like a factor of 2 in the relative wear rates. At the same time, such comparisons made it very clear that some additional and more potent effect would need to be invoked in order to account for the quantitative magnitude of the observed anomaly in our wear rates—some nonlinear effect, or perhaps an abrupt load-sensitive transition of some kind in the basic nature of the stylus-groove contact.

As often happens on the frontiers of applied science, this problem had to be allowed to languish until a better understanding had been achieved in other areas concerning such fundamental questions as the nature of wear and friction, of lubrication, and of the factors that control the strength of solid materials. This understanding is still far from complete, but fortunately, the accelerated pace of basic research by metallurgists and solid-state physicists has already uncovered one phenomenon that appears to have an unsuspected relevance to the phonograph problem. To put it more specifically, the kernel of these speculations is the hypothesis that the same physical factors that give rise to a "size effect" in the strength testing of materials can account for just the kind of abrupt transition in the elastic-plastic regime prevailing under the stylus contact that is needed in order to explain the observed rates of wear, both conventional and anomalous. Before offering such an explanation, however, we will need to make a few detours in order to build a foundation for the conclusions.

[1] Benjamin B. Bauer, "Wear of Phonograph Needles," *Trans. I.R.E., Professional Group on Audio* (November, 1951).

[2] F. V. Hunt and J. A. Pierce, "Phonograph Reproducer Design," *J. Acoust. Soc. Amer.*, **12**, 474 (A) (January, 1941); also U. S. Pats. No. 2,239,717 (filed August 2, 1938; issued April 29, 1941) and No. 2,369,676 (filed July 10, 1940; issued February 20, 1945).

THE SIZE EFFECT

The term "size effect" is used to characterize the experimental observation that many, and perhaps all, solid materials exhibit very much higher yield strength when minute specimens are examined than when the same materials are tested in bulk. For example, glass fibers that are only a few microinches in diameter are found to have a tensile strength many times higher than the handbook values,[3] and the tiny "whiskers" that appear when some metals are crystallized from the vapor phase show the ability to withstand strains many times greater than those which would produce fracture in large polycrystalline specimens of the same material.[4] An oversimplified qualitative explanation of this behavior can easily be offered: A "flaw" in such a slender fiber would occupy a substantial portion of the cross section and would lead to premature fracture. Only those without such flaws survive for testing, and these exhibit very nearly the so-called "theoretical" yield strength.

Another example of the size effect that is more closely related to the phonograph problem has been turned up recently in studies of the physical principles involved in microhardness testing. These tests turn out to be remarkably like the experiments carried out every day in millions of homes by people who think that they are just playing phonograph records! An impressed load force acting on a diamond indenter causes it to penetrate the surface of the material and produce a permanent indentation. The so-called microhardness number then expresses (in kg/mm^2) the mean pressure on the projected area of the indenter which the material supports without further yielding. Note that some plastic yielding always does occur in these tests, however, as evidenced by the permanent indentation. The importance of these techniques for our purposes stems from the fact that Tabor and others[5] have shown that the effective yield strength, Y, of the material can be deduced from such measurements, and that its magnitude lies between 1.1 and 3 times the mean pressure represented by the microhardness number.

The size effect reveals itself in indentation tests as a progressive increase of the apparent microhardness as the load force on the indenter is reduced below the values that produce a depth of penetration of about one micron or less.[6]

[3] A. A. Griffith, "Phenomena of Rupture and Flow in Solids," *Phil. Trans. Roy. Soc. (London)*, **A221**, 163-198 (1920).

[4] C. Herring and J. K. Galt, "Elastic and Plastic Properties of Very Small Metal Specimens," *Phys. Rev.*, **85**, 1060-1061 (1952).

[5] For bibliography and discussion of principles of indentation tests, see D. Tabor, *The Hardness of Metals*, Chapters II and IV-VI, Clarendon Press, Oxford, 1951.

[6] Milton C. Shaw, "A Yield Criterion for Ductile Metals Based Upon Atomic Structure," *J. Franklin Inst.*, **254**, 109–126 (1952).

Experimental data illustrating this effect for phonograph record materials are lamentably meager, but I was gratified to find that the indentation tests made in 1949-1950 by Dr. F. G. Miller,[7] in connection with his study of the effects of groove-wall compliance, can indeed be interpreted in this way. I am now indebted to Dr. T. J. Schultz of our laboratory for repeating and extending these measurements. His results are exhibited in Fig. 1, which shows the width of the residual indentation track left when a 1-mil or 3-mil spherical stylus subjected to various bearing loads is drawn over an ungrooved portion of the surface of an unfilled vinylite pressing. These experimental data can also be presented in the more useful form shown in Fig. 2, where each curve has been replotted in terms of the mean pressure on the circle of contact, defined as $P_m \doteq 4W/\pi d^2$.

Two remarks about Figs. 1 and 2 need to be made in passing. In the first place, it may come as a minor shock

[7] F. G. Miller, Doctoral Dissertation, Harvard University, 1950. Results summarized in F. V. Hunt, "Stylus-Groove Relations in the Phonograph Playback Process," *Acustica*, 4, 33–35 (1954).

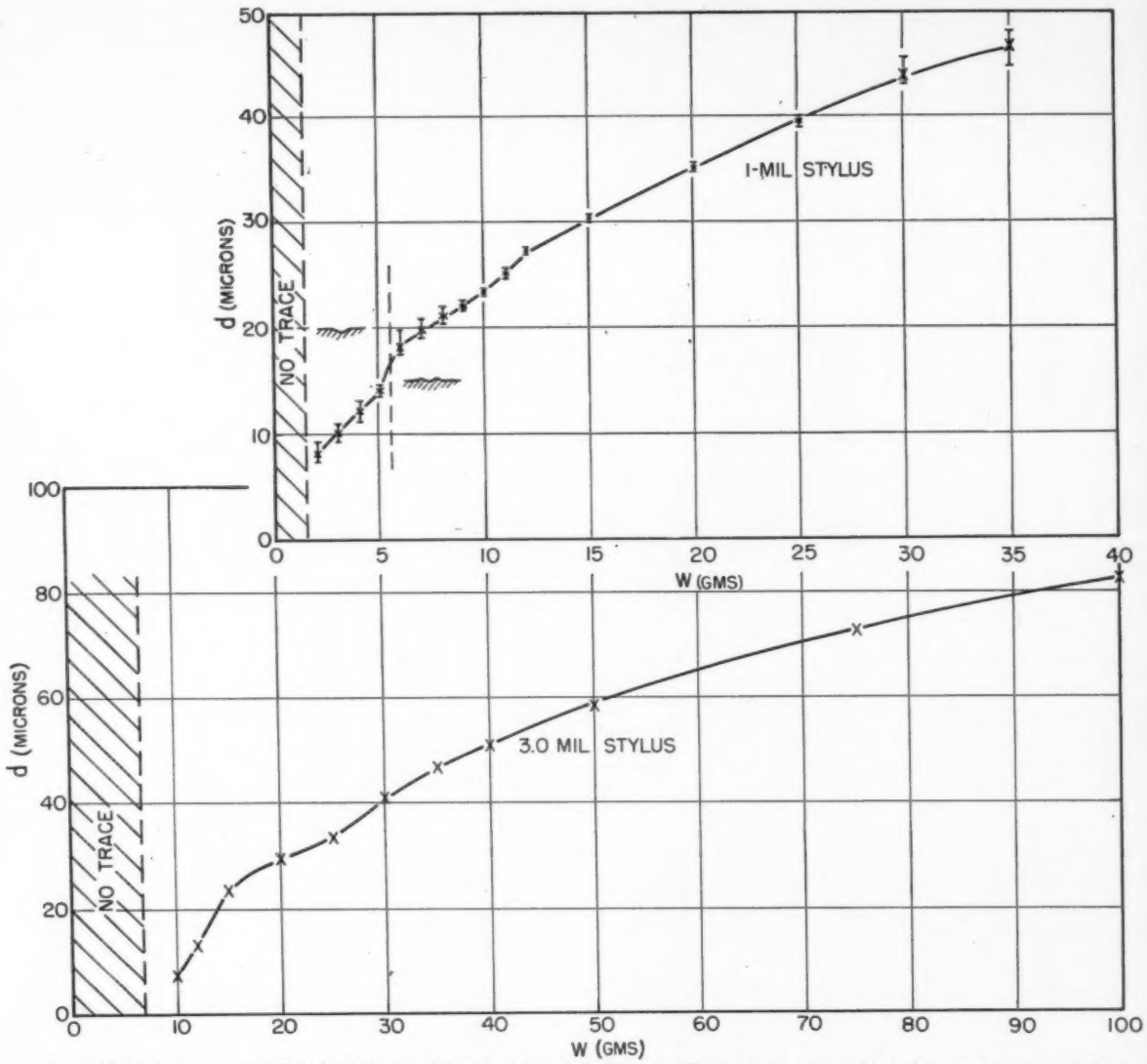

FIG. 1. Width of the residual indentation tracks made when a 3-mil or 1-mil spherical stylus subjected to various bearing loads is drawn slowly over the ungrooved surface of a clear (red) unfilled vinylite pressing.

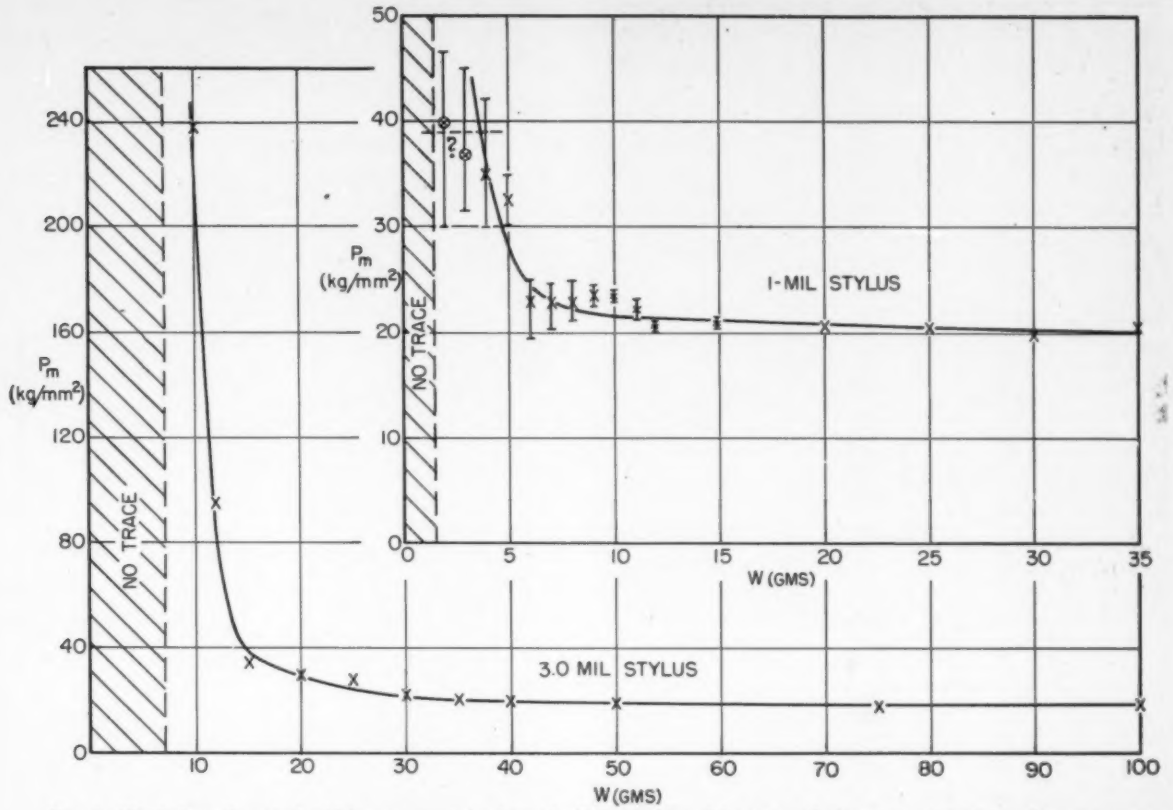

FIG. 2. The indentation track-width measurements shown in Fig. 1 replotted in terms of the apparent mean bearing pressure on the circle of contact, defined as $P_m = 4W/\pi d^2$.

to observe that conventional phonograph styli subjected to conventional bearing loads and operating on standard record materials can and do produce a permanent indentation. The residual track is narrow, to be sure, and a good bit of experimental ingenuity in arranging contrasting illumination is required in order to show the track up clearly enough to allow it to be measured. But the indentation track is certainly there, as demonstrated by the microphotograph of Fig. 3, which shows a typical example (about a third of a mil wide and 22 microinches deep) produced by a 2-gram load on a 1-mil stylus on unfilled vinylite. It is an inescapable conclusion, therefore, that, under the conditions assumed here as "conventional," the stylus-groove contact is controlled, at least to an important degree, by plastic yield considerations rather than by elasticity.

The second remark takes the form of a renewed appeal for avoidance of the term "needle pressure" in connection with the description of phonograph pickups. The bearing pressure on the stylus contact is indeed an important and useful parameter of the stylus-groove contact, but it is controlled primarily by the record material rather than by the stylus loading! If there remain any diehards who would insist that "stylus pressure" and "stylus force" are just different ways of describing the same thing, let them give heed to Fig. 2, which shows that within the range of variables arising in current phonograph practice, the stylus pressure actually increases, rather than decreases, when the stylus force is reduced.

A useful mathematical description of the size effect can be devised even without identifying (or understanding) in detail the nature of the "flaws" that control the gross yield strength of plastic record materials. What is needed is the evaluation of a weighted statistical mean, or "effective," yield strength lying somewhere between an upper limit corresponding to the "theoretical" yield strength, $Y_0 + Y_1$, that would be exhibited by a wholly flawless specimen, and a lower limit, Y_0, corresponding to the yield strength of a bulk specimen having a typical population and distribution of flaws. In formulating the effective yield strength $Y(V)$ for a particular specimen of volume V, it is plausible to assume that the two limiting values of Y should be weighted according to the probabilities of either finding or not finding

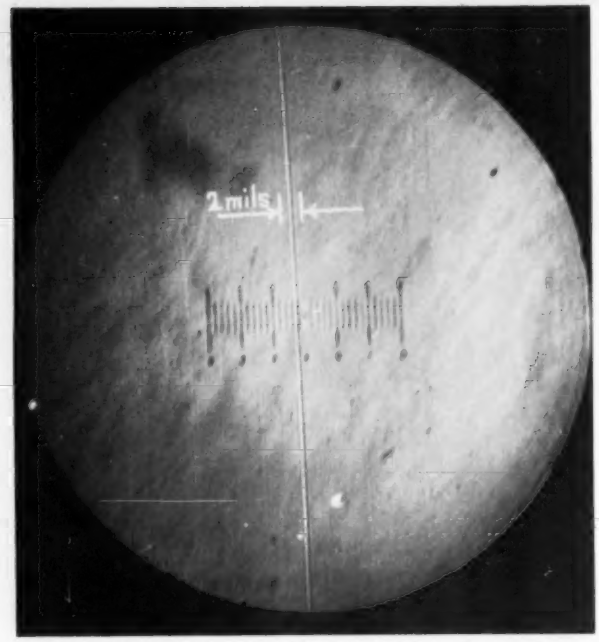

FIG. 3. Microphotograph of the indentation track made in unfilled vinylite (red) by a 1-mil stylus (spherical indenter) with a 2-gram load. Track width, 9.50 microns.

a flaw within the volume V. Thus, if there are on the average K flaws or structural imperfections per unit volume, and if the statistical distribution of these flaws throughout the material is normal, then the probability that the volume element V will *not* contain a flaw will be just e^{-KV}. It follows, of course, that the corresponding probability that V *will* contain a flaw is just $1 - e^{-KV}$. The effective yield strength can then be written at once as

$$Y(V) = (Y_0 + Y_1)\, e^{-KV} + Y_0 (1 - e^{-KV}) = Y_0 + Y_1\, e^{-KV} \qquad (1)$$

The studies of hardness testing referred to above[5] have shown that the gross yield strength Y_0 can, with some confidence, be taken as equal to ⅓ the constant mean pressure P_m that prevails when the indenter is loaded heavily enough for the plastic state to be fully developed throughout the region of contact. Since this condition appears to be adequately satisfied for the loadings that produce the horizontal portions of the curves of Fig. 2, it follows that the value of Y_0 needed for eq. 1 is approximately 6.5 kg/mm² for clear (red) unfilled vinylite. Unfortunately, however, some of the secondary factors (such as elastic "recovery," increasing difficulty of measuring indentation, etc.) that contribute to the empirical nature of hardness testing begin to assume greater importance for just the conditions of light loading that produce the greatest enhancement of the yield strength. Partly for this reason, and partly on account of the size effect itself (see below), numerical values for the upper limit of the yield strength, $Y_0 + Y_1$, have remained relatively elusive, even for metals; and almost no effort has yet been devoted to establishing even the order of magnitude of the "theoretical" yield strength for the plastics used for phonograph records. Crude values for K and Y_1 can be wrung from the data presented in Fig. 2 by a process of curve fitting, but more extensive measurements, and perhaps other methods of testing, are needed in order to allow the size effect to be characterized analytically with adequate precision. In view of this state of numerical ignorance, it is comforting to observe that the qualitative conclusions to be drawn below do not depend in any critical or sensitive way on the quantitative details of the formulation expressed by eq. 1.

STRESS DISTRIBUTION IN THE REGION OF CONTACT

Consider now the magnitude and distribution of the elastic stresses in the record material adjacent to the stylus contact for the "wholly elastic" regime in which no plastic yielding occurs. The upper part of Fig. 4 shows the assumed geometrical situation, and the notation to be used can be summarized as follows:

a, d = radius and diameter of the circle of contact;
R = radius of the spherical tip of the stylus;
h = maximum penetration, at the center of the circle of contact, measured from the plane surface;
D = diameter of a "flat" on the spherical stylus tip;
W = "bearing load" on the stylus (mass units);
$F = Wg$ = "stylus force" (force units);
$P_m = W/\pi a^2$ = mean "bearing pressure" on the circle of contact;
P_0 = maximum pressure (at the center of the circle of contact);
E, ν = Young's modulus and Poisson's ratio for the record material;
$\sigma_r, \sigma_\theta, \sigma_z$ = the three principal stresses in the radial, tangential, and normal directions;
τ = shear stress.

The general solution given by Hertz for the elastic contact of two spheres is simplified extensively when one of the spheres expands to become the plane surface of a groove wall and when the other can be assumed to be ideally rigid (that is, when the elastic modulus of the stylus is very much larger than that of the record material). For this case, the radius of the contact circle can be expressed as

$$a^3 = \frac{3}{4}\frac{FR}{E'}, \quad a = \frac{3\pi}{4}\frac{R}{E'}P_m \qquad (2)$$

where E' is an abbreviation for $E/(1-\nu^2)$, the plane-stress or "constrained" value of Young's modulus†. If a is eliminated between the two forms of eq. 2, the mean bearing pressure can be expressed in terms of the stylus loading as follows:

$$P_m = \frac{1}{\pi}\left(\frac{16}{9}\right)^{1/3}\left(\frac{E'^2}{R^2}W\right)^{1/3} = 0.45\frac{E'^{2/3}}{R^{2/3}}W^{1/3}\text{kg/mm}^2 \quad (3)$$

where the numerical factor in the second part has been adjusted to allow W to be expressed in grams, E' in kg/mm^2, and R in mils. It may be noted in passing that, for the elastic regime presumed in writing eq. 3, the stylus force must vary directly as the *square* of the stylus radius in order to maintain a constant stylus pressure. It follows that if the groove-wall deformations were to remain elastic, the current practice of reducing the stylus force by a factor of only 2 or 3 when shifting from a 3-mil to a 1-mil stylus would correspond to designing for substantially higher bearing pressures on microgroove records. On the other hand, plastic yielding actually does occur for conventional loadings in both cases, and as always, in such a way as to reduce or relieve the stresses. The designed excess of pressure on microgrooves largely disappears for this reason, as shown by Fig. 2; but the designer can draw little comfort from this, since the same yielding that relieves the pressure leads also to severe increase in the wear rate (see below).

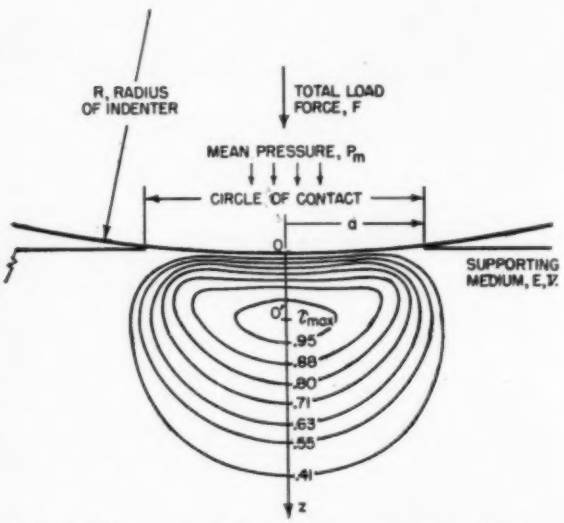

FIG. 4. The geometry of the stylus-groove contact, and a stress-contour diagram showing the distribution of the maximum difference between the principal stresses in the region underlying a spherical indenter. The number on each contour indicates its "height" in terms of the highest shear stress, which occurs at the point O' located about half a contact-circle radius below the center of contact at O. *(After Davies[9])*

The maximum normal stress, P_0, on the bearing surface occurs at O, the center of the contact circle, and is 3/2 the mean bearing pressure, P_m. It has been known for a long time,[8] however, that the highest shear stress in the supporting medium does not occur at the surface of contact, but rather at an interior point O' lying below the center of contact by about half the radius of the contact circle (see Fig. 4). Several investigators have computed numerically the stress distribution under a spherical indenter, in order to plot the slip-line field, and Davies[9] has exhibited the largest difference between the principal stresses in the form of the contour diagram shown in the lower part of Fig. 4. The magnitude of this stress difference at points lying on the z-axis can be expressed in closed form by integrating (with the help of a change of variable) the relations given by Timoshenko[8] for the simpler case of uniform loading over the surface of contact. The stress difference found in this way is

$$2\tau(z) = \sigma_\theta - \sigma_z = \sigma_r - \sigma_z = \frac{3}{2}P_m\left[\frac{3}{2}\frac{1}{1+z^2/a^2} - (1+\nu)\left(1-\frac{z}{a}\operatorname{ctn}^{-1}\frac{z}{a}\right)\right] \quad (4)$$

where $\tau(z)$ is the shear-stress distribution along the z-axis. Note also that two of the principal stresses, σ_r and σ_θ, are equal by virtue of symmetry. A typical graph of eq. 4 is shown in Fig. 5. Both the height and position of the maximum of this curve are weakly influenced by the value of Poisson's ratio, as may be shown by solving numerically the equation formed by setting the derivative of eq. 4 equal to zero. For values of ν lying between 0.25 and 0.40, the position of highest stress is found in this way to be

$$\left(\frac{z}{a}\right)_{max} = 0.381 + \frac{1}{3}\nu \quad (5)$$

† "g"-trouble rears its head at this point when one approaches eq. 2 or its descendants with numerical intent. In the literature on hardness testing, with which it seems useful to maintain numerical compatibility, it appears to be common practice to divide the "E" out of P_m with the result that pressure then has the apparent dimensions of mass loading per unit area; but since E is also expressed in the same units, consistency is maintained. I do not defend the ambivalence, but in this text all stresses (E, Y, τ, σ) are to be expressed in terms of *force* per unit area when they occur along with F, but in terms of *mass* per unit area when they are associated with P_m or W.

[8] S. Timoshenko and J. N. Goodier, *Theory of Elasticity*, 2nd ed., pp. 362-377, McGraw-Hill Book Co., New York, 1951.

[9] R. M. Davies, "The Determination of Static and Dynamic Yield Stresses Using a Steel Ball," *Proc. Roy. Soc.* (*London*) **A197**, 416-432 (1949).

and the corresponding maximum stress difference is

$$(\sigma_r - \sigma_z)_{max} = \tfrac{3}{2} P_m (0.756 - 0.450\,\nu) \qquad (6)$$

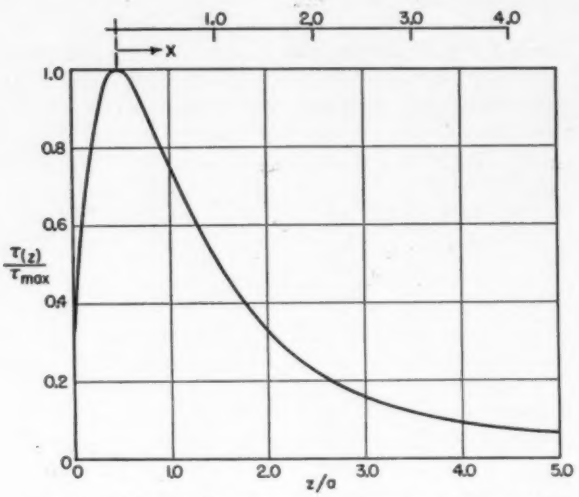

FIG. 5. Typical variation along the normal axis of the elastic shear stress under a spherical indenter.

THE CRITERION FOR YIELDING

A further consequence of the symmetry that makes two of the principal stresses equal on the z-axis is that the Huber-von Mises, the Tresca-Mohr, and the Haar-von Karman criteria for the onset of plastic yielding all agree in predicting that yielding will begin at the critical load that just satisfies the limiting equality expressed by

$$\sigma_r - \sigma_z \leq Y(V) \qquad (7)$$

The physical significance of this yield criterion must now be interpreted with due regard for the distribution of elastic stresses represented by the contours of Fig. 4, and for the influence of the size effect represented by the functional dependence of yield strength on the volume of the stressed specimen. One may observe qualitatively that the stress decreases from one contour to the next in moving away from the point of highest stress, in a manner governed by eq. 4 and that, as the volume of stressed material contained within successive contours increases, there will be a corresponding reduction of yield strength governed by eq. 1. Whether the stress difference will first exceed the yield strength at the point of highest stress, O', or at some other point along the z-axis, will obviously depend on the respective rates at which these quantities vary along the z-axis.

One preliminary conclusion can be drawn at once by inspection of the stress-contour diagram. The increments of volume are smaller between O and O' than on the other side of O'; from which it follows that, while yielding may commence either at the highest-stress point or beyond, it can never begin in the region between O' and the center of contact. As a consequence, only the portion of the stress-distribution curve lying beyond the maximum needs to be considered in exploring the conditions for the onset of yielding. It also follows that this controlling portion of the stress curve can be expressed most usefully in terms of a new dimensionless position variable, x, whose origin is placed at O', as indicated by the x-scale annexed to Fig. 5. Thus, by incorporating eq. 5 to make the definition explicit,

$$x \equiv \left(\frac{z}{a}\right) - \left(\frac{z}{a}\right)_{max} = \left(\frac{z}{a}\right) - \left(0.381 + \frac{1}{3}\nu\right) \qquad (8)$$

In terms of this variable, the yield-controlling stress difference can be described very simply as

$$\sigma_r - \sigma_z = \tfrac{3}{2} P_m f_1(x), \qquad x \geq 0 \qquad (9)$$

in which the stress-distribution function $f_1(x)$ stands as an abbreviation for the bracketed terms in eq. 4 modified by the change of variable. Finally, since the bearing pressure P_m can only be controlled indirectly, it is useful to go one step further and use eq. 3 to replace P_m with the variables that are experimentally accessible. This step leads to the convenient working relation for the stress-difference, or shear-stress distribution,

$$2\tau = \sigma_r - \sigma_z = 0.578 \frac{F^{1/3} E'^{2/3}}{R^{2/3}} f_1(x) \qquad (10)$$

Consider next the yield strength given by eq. 1. To put this in a form better adapted for the specified comparison of stress and yield strength, let us first express the volume of material enclosed within any stress-difference contour in terms of the value of x at which the contour cuts the z-axis. Such a relation might be written arbitrarily in the form

$$V = \frac{4}{3} a^3 f_2(x) = \frac{FR}{E'} f_2(x) \qquad (11)$$

where the factor a^3 is first introduced in order to normalize the dimensions and is then eliminated (by substitution from eq. 2) in order to put in evidence again the experimental variables. The function $f_2(x)$ is defined arbitrarily to include any leftover numerical factors as well as the volume distribution function. It would not be easy (to say the least) to derive a closed-form analytical expression for $f_2(x)$, owing to the complex nature of the three-dimensional stress field. On the other hand, it is not difficult—just tedious—to compute by numerical integration the volumes corresponding to the seven particular contours shown in Fig. 4. A log-log graph of these results, as shown by Fig. 6, then reveals that the enclosed volume begins to increase as x^3 for small values

of x less than about 0.3, and then increases less rapidly, approximately as $x^{1.7}$, for larger values of x. Usable values of $f_2(x)$ can be read directly from such a graph, but it is somewhat more convenient numerically to represent this function by the empirical equations

$$f_2(x) \doteq 13.6\,x^3, \quad \text{for } x < 0.3 \qquad (12)$$
$$\doteq 3.2\,x^{1.7} \quad \text{for } x > 0.3$$

With the volume distribution function thus in hand, we can proceed to put eq. 11 in eq. 1, whereupon the working relation for the effective yield strength takes the form

$$Y = Y_0 + Y_1 \exp\left[-\frac{FRK}{E'} f_2(x)\right] \qquad (13)$$

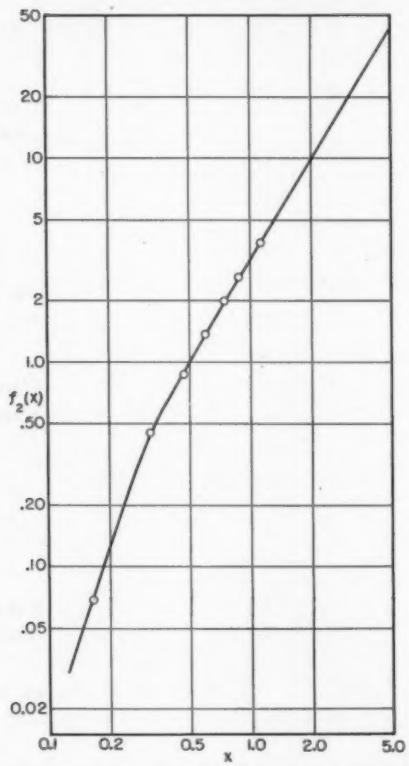

FIG. 6. Log-log graph of the function $f_2(x) = 3V/4a^3$, where V is the volume of material enclosed by the stress-difference contour passing through x.

CONDITIONS FOR THE ONSET OF PLASTIC YIELDING

The physical significance of the criterion for plastic yielding expressed by eq. 7 can be restated as follows. Any combination of the experimental variables F and R and of the material constants E', Y_0, Y_1, and K which produces stress differences (eq. 10) that are less than the yield strength (eq. 13), for *all* values of x, will produce deformations that are wholly elastic. Recovery will be complete in these cases after the stylus has moved on and thereby removed the load. On the other hand, when any combination of these six parameters first allows equality to be achieved between stress difference and yield strength, at *any* value of x most favorable for such equality, then plastic yielding will begin at the point on the x-axis corresponding to this most-favorable value of x.

What happens *after* yielding has commenced is another question, and one on which the yield criterion itself is mute. Energy considerations require that yielding always proceed in such a way as to relieve, and hence to reduce, the causal stresses; and it is safe to add that the rate of plastic flow will increase with the excess of the stresses over those that can be supported by elastic strains. Our state of ignorance about the *rates* of plastic flow under a phonograph stylus would be downright embarrassing, were it not for the fact that in what follows it will be argued that any plastic flow at all is highly undesirable on grounds of both wear and noise, and that the pickup designer dare not rest until he achieves the safe quiet haven of the fully elastic regime!

One important feature of eqs. 10 and 13 can be pointed out that makes it possible to draw useful generalizations about the threshold of plastic yielding in spite of the large number of disposable parameters. For example, the variables F, R, and E' enter only as multipliers in eq. 10, and hence will influence the *scale* but not the *form* of the functional relation between the stress difference and x. As a consequence, the log-log graph of $(\sigma_r - \sigma_z)$ versus x will have a constant shape and will be merely translated upward or downward by changes in these multiplying factors. This behavior is indicated by the direction arrows superposed on the typical stress-difference curve shown in Fig. 7.

The functional relation between the yield strength and x also reveals the influence of the experimental variables in a no less useful, but different, way. It can be seen, either by inspection of eq. 13 or by plotting a few typical curves, that the *shape* of a log-log graph of Y versus x will consist of two horizontal segments, corresponding to the limiting values Y_0 and $Y_0 + Y_1$, joined by an S-shaped transition curve that rises steeply at a value of x that will depend on the multiplying factors that appear along with $f_2(x)$ in the exponent. Thus in this case it is the *lateral* position of the steeply rising portion of the yield curve that shifts with F, R, E', and the flaw constant K, as indicated by the direction arrows superposed on the yield-strength curve shown in Fig. 7.

The two curves of Fig. 7 thus provide an objective representation of the stress differences and the yield strengths that must be in balance at the threshold of yielding, and

these can readily be manipulated in hypothetical experiments, thanks to the fact that each curve can be regarded as if it were a plane bent-wire figure—rigid, but freely movable in the coordinate plane. The various conditions attending the onset of plastic yielding can then be surveyed by observing where these two curves first become tangent as each is shifted at the rate and in the direction called for by changes in the several parameters. Four cases of particular interest can be identified.

(*a*) *Large-radius indenter.* Large values of the radius R tend to depress the "starting" position of the stress curve (since $R^{2/3}$ appears in the denominator of eq. 10), and to displace the initial position of the transition segment of the yield curve relatively far to the left on the log x-axis. As a consequence, when the load force F is progressively increased, the stress curve shifts upward and the transition segment of the yield curve moves still farther toward the left, until first tangency occurs at the vanishingly small values of x corresponding to O', the interior point of highest shear stress, as shown at T_a in Fig. 8a. Note that the size effect enhancement of the yield strength plays no part in controlling the onset or course of plastic yielding in this case, and that the maximum elastic stress which can be sustained at the threshold of yield corresponds to $P_m \doteq 1.1\ Y_0$. This is the typical situation that prevails in all conventional hardness tests that make use of spherical indenters 1 mm or more in diameter.

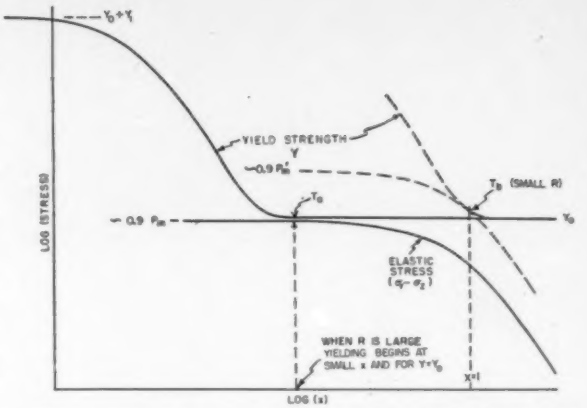

FIG. 8a. The solid curves show that the "bulk" value of yield strength controls the onset of plastic yielding for a large-radius indenter. The dashed curves show how the point of tangency can occur beyond the knee of the yield curve, with a corresponding enhancement of the yield pressure, when the indenter radius is small.

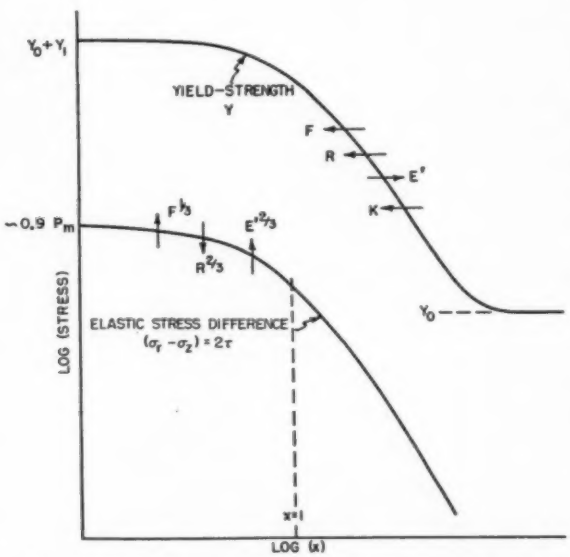

FIG. 7. Typical log-log graphs showing, as a function of x, the elastic stress difference and the effective yield strength for a hard spherical indenter penetrating the plane surface of an extended medium. The arrows show how the indicated parameters act to translate the curves without change of shape. An assumed value of $(Y_0+Y_1)/Y_0=20$ was used in computing the yield curve.

(*b*) *Small-radius indenter—marginal case.* As the radius of the indenter is made progressively smaller, the transition segment of the yield curve will shift to the right on the log-x scale and there will turn up eventually some small value of R for which the yield curve will occupy a position such as shown by the dash-line curve of Fig. 8a. For this case the point of tangency T_b will begin to occur "just around the corner" of the lower bend of the transition segment and at a point near the knee of the stress curve at which $x \sim 1$. Since x is a measure of the distance from O', in units of a, it follows that plastic yielding would begin in this case at a point about $3a/2$ below the surface. This does not mean that the point of highest shear stress has retreated farther from the surface, but rather that the small volume of material in the immediate neighborhood of the point of highest stress is being protected against yielding, as it were, by the size effect. What is most important for our purposes, however, is that the mean bearing pressure P_m' that can be sustained elastically without yielding is substantially higher than would be predicted in the absence of a size effect.

It will be apparent that the magnitude of this enhancement of the supportable pre-yield elastic stress will depend on how far up on the yield curve the point of first tangency occurs, and that this will in turn depend on the radius R and on the material parameters E', K, and Y_1/Y_0. The illustrative curves of Fig. 8a show a 2.5-fold elevation of the elastic stress, with the critical yield point (i.e., tangency) at $x = 1$, for an assumed value of $Y_1/Y_0 = 19$. It can then

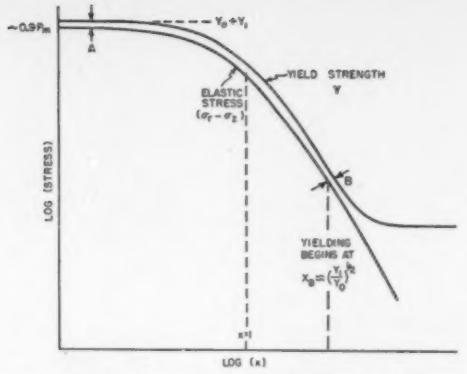

FIG. 8b. The critical case of elastic-plastic instability for which plastic yielding may start simultaneously throughout an extended region underlying the circle of contact.

be shown, by numerical manipulations with eqs. 13, 6, and 3, that these assumptions require, for consistency, that $R \doteq 0.16\ E'Y_0^{-1}K^{-\frac{1}{2}}$; but none of these parameters is known with enough precision to allow the quantitative relevance of this case to the phonograph stylus problem to be argued conclusively. On other grounds, however—notably on the basis of the data for Fig. 2—there is reason to believe that this case does embrace the situations that prevail in current phonograph practice. In particular, it seems likely that it is just such an enhancement of the pre-yield elastic stress that prevents the designed excess of bearing pressure on microgrooves from causing even more trouble than it does.

A speculative gleam may well appear in the designer's eye at this juncture. It might be that vulnerability to plastic yielding could actually be reduced by still further reduction of the stylus-tip radius to half a mil or less. Unfortunately, the quantitative information about record materials in general, and about the parameters Y_1 and K in particular, is still too sketchy to allow such a proposal to be assessed. The potential advantages of such a change of system parameters would suggest, however, that it may be worthwhile to pursue the needed data with some vigor.

(*c*) *Small-radius indenter—the critical case of elastic-plastic instability.* It can be seen that as the radius is made slightly smaller than assumed for case *b*, or when any changes in the other parameters combine to produce an equivalent displacement of the stress and yield curves, there will always arise one critical juxtaposition of these curves for which tangency will occur—and hence for which plastic yielding will be initiated—simultaneously at both a large and small value of x.

For example, suppose that the parameters are such that the stress and yield curves have the relative positions shown in Fig. 8b. When first tangency almost—but not quite—occurs in the region *A* of Fig. 8b, the deformation remains wholly elastic and enjoys the "protection" of a yield strength nearly equal to the "theoretical" upper limit $Y_0 + Y_1$. A slight further increase of load force, however, will bring the stress curve into contact with the yield curve not only at *A*, but also at *B*, and plastic yielding will at once be precipitated throughout the volume of material bounded by the stress contour passing through x_B. The region so affected may extend into the underlying medium by as much as several times the diameter of the contact circle, depending on the relative magnitudes of Y_0 and Y_1. In a static indentation test, this type of instability could only manifest itself for increasing loads inasmuch as plastic yielding is not reversible. For the *sliding* contact of stylus on groove wall, however, new material is constantly being presented to the stylus, the situation can be regarded as statistical, and a relatively abrupt transition from the plastic to the elastic regime can equally well appear on reduction of the load. This is, therefore, just the kind of "abrupt load-sensitive transition in the basic nature of the stylus-groove contact" that was referred to above in the introduction.

(*d*). *Very-small-radius indenter.* For all values of the indenter radius smaller than the one that gives rise to the critical instability of Case (*c*), the whole transition segment of the yield curve will have been displaced to the right beyond the stress curve, as shown in Fig. 8c. Tangency can only occur then at vanishingly small values of x, and for a controlling value of the yield strength near the upper limit $Y_0 + Y_1$. In effect, the volume of material "protected" against yielding by the size effect includes all the region within which the elastic stress difference is higher than Y_0. As a consequence, yielding will begin only when the stress difference exceeds the upper limiting yield strength, and it

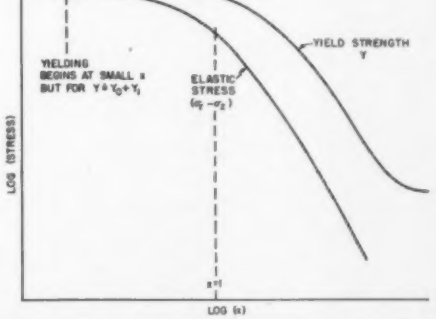

FIG. 8c. For a very-small-radius indenter, such as a submicroscopic "high" point on a "smooth" surface, the deformation may remain elastic for stresses nearly equal to the theoretical yield strength.

will do this first at O'. This is the typical situation that prevails in the localized areas, or asperities, at which a solid material makes "real" contact with its load. It can also be said that the conventional stylus-groove contact appears to come just close enough to falling within this category to make the eventual attainment of its high-stress, elastic regime a realistic design objective for phonograph playback systems.

THE AREA OF REAL CONTACT AND RUBBING WEAR

The mysteries of sliding friction and wear have challenged the intellectual curiosity of scientists since antiquity. A clear understanding of the facts behind the facts is still far from complete, but recent studies[10] have evolved a plausible model of the mechanism of mechanical interaction that has at least the virtue of simplicity and perhaps that of adequacy. Many of the details of this model are still controversial, of course; and there is, as usual, a lamentable scarcity of quantitative data relating to the materials and circumstances of phonographic interest. Nevertheless, the basic conceptions that have been advanced to explain the behavior of dry metals in sliding contact will serve as a useful framework for these speculations about stylus wear.

Solid surfaces are never ideally smooth and flat. It is not widely appreciated, however, that the surface of a freshly-cut groove in a lacquer record is one of the smoothest surfaces known to exist. For example, if it is safe to assume that a 10-kcs sine wave can be reproduced at a level 40 db above the overall background noise in a 12-kcs playback channel, then it can be shown that the root-mean-square "roughness" of the groove surface must be of the order of magnitude 50 Å, or about 1/100 of a wavelength of visible light. In spite of this remarkable degree of smoothness, it must be conceded that even such a surface will have a statistical distribution of irregularities that represent departures from ideal smoothness many times larger than the average spacing between neighboring atoms of the surface material. These surface irregularities will, in fact, be larger than the interatomic spacing by several orders of magnitude in all but the most ideal cases.

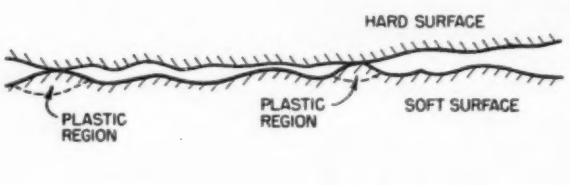

FIG. 9. Diagrammatic representation of two contacting surfaces that make "real" contact only in localized areas. The upper part shows how light loads are carried by only a few points of real contact; the lower part shows the spreading area of real contact under heavier loads and illustrates the entrapment of an abraded wear particle. *(After Burwell and Strang[15])*

[10] F. P. Bowden and D. Tabor, *The Friction and Lubrication of Solids*, Clarendon Press, Oxford, 1950; J. T. Burwell, ed., *Mechanical Wear*, American Society for Metals, 1950; also, many additional references cited in each of the foregoing.

It must follow then, that even when two very smooth surfaces are brought lightly together, "real" contact will be made only at the tips of the high points, or asperities, of the mating surfaces. The area of real contact between each asperity and its mating surface will increase as the load force increases, moreover, in much the same way that the surface of contact increases in area when the load is increased on a spherical indenter of macroscopic size. In addition, progressive deformation of the highest asperities will allow other high points to come into real contact. Increasing loads serve, therefore, to increase both the number and the size of the local areas in real contact. It can be seen that the total area of real contact, A_{re}, will be directly related to the total force acting, and that this area of real contact is not related in any essential way to the apparent area of the contacting surfaces.

The physical situation thus assumed to exist in the region of contact between two surfaces is illustrated diagrammatically in the upper half of Fig. 9, which shows two typical asperities making "real" contact. The actual size of typical asperities, even for very smooth surfaces like those of the stylus and groove, is almost surely small enough to qualify under case *d* discussed above, and hence the micro-yield strength Y_μ, that would be effective throughout the volume of the small asperity will be

$$Y_\mu \doteq Y_0 + Y_1 \qquad (14)$$

Case *d* teaches that plastic yielding will begin at the tip of the asperity when the local mean bearing pressure reaches about $1.1Y_\mu$. The studies of hardness testing[5] go further, however, and say that as the plastic state becomes fully developed under an indenter (represented by the asperity in this case), the local mean pressure gradually rises to about $3Y_\mu$.

The existence of supra-yield stresses throughout the volume of a local asperity does not imply necessarily that the underlying material is also in the plastic state. These high stresses will diminish toward the base of the asperity where it broadens at its junction with the basal plane, and may—in fact, had better—become small enough in that region to

produce only elastic deformation of the base material. Of course, the regime that does prevail at any point in the base material will be determined by the resultant of all the stresses transmitted from all the nearby asperities. The net effect of these considerations is to leave unaffected the conclusions drawn above in cases *a–d* regarding the onset of plastic yielding in the base material. Only in dealing with wear and friction is it necessary to notice the difference between the real and apparent area of contact, but for these two problems the difference is crucial.

The circumstances described above are illustrated schematically by the profilometer traces[11] shown in Fig. 10. The actual scale of these original traces was macroscopic, rather than submicroscopic as in the case discussed here, but the descriptive analogy is complete. Traces *A* and *B* show that the tips of these "asperities" experienced plastic deformation from which they did not recover, but that the deformation of the base material was elastic and its recovery essentially complete. Under the loading for trace *C*, the base material also was deformed plastically and a permanent indentation of the "mean surface" remained after the load was removed.

Conceiving the mechanism of contact between solids to consist of a myriad of small local areas in intimate real contact provides the framework for a phenomenological theory of the wear process. First assume that a typical "wear particle" can be identified, and that the average distance between such particles is a. Then the total number of such particles lying in each surface of all the areas of real contact will be A_{re}/a^2. Moreover, since the average inter-particle spacing is a, a sliding motion of the stylus through the distance L will bring each single particle lying in the stylus surface into intimate juxtaposition with L/a particles of the groove surface. It follows that when the stylus has travelled a distance L, there will have occurred, on the average, $L\,A_{re}/a^3$ encounters or near-approaches between particles of the two surfaces. We now make the crucial assumption that in every such encounter there is a fixed probability, Z, that one of the stylus particles will be removed, or abraded from its parent surface either by adhering to the groove surface or by acquiring from the encounter a sufficient surplus of vibrational energy. According to this notion, the total number of particles liberated from the stylus surface will be ZLA_{re}/a^3; and since the number of particles contained in a volume V is just V/a^3, the total volume of stylus material abraded or worn away in travelling a distance L will be given by the simple relation

$$V = ZA_{re}L \tag{15}$$

When this elegantly simple theory of rubbing wear was proposed originally by Holm,[12] he assumed that the abrasive attrition would be atomic in character. Burwell[13] has pointed out, however, that the theory is not impaired if Holm's atoms are replaced (as in the foregoing discussion) by small "wear particles," and he supports this substitution by showing that typical wear particles removed from hardened steel surfaces fall within the size range 50 to 100 Å. Although it may be only coincidental, one cannot fail to be

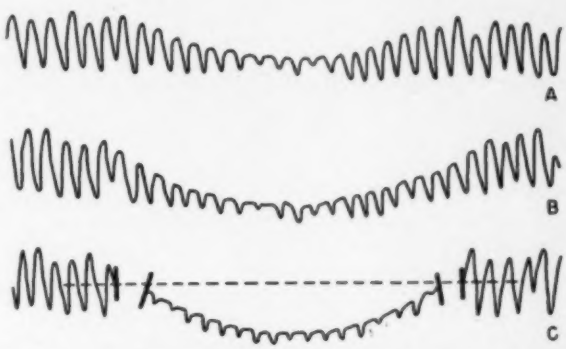

FIG. 10. Profilometer traces of the deformation of a finely grooved metallic surface. These macroscopic profiles illustrate schematically the assumed behavior of submicroscopic asperities at the stylus-groove interface. *(After Moore[11])*

impressed by the inviting similarity between the size of Burwell's steel wear particles, the residual roughness of a very quiet groove, and the typical dimensions of the large molecular aggregates that characterize plastic polymers. Has anybody studied size distribution in the sapphire dust embedded in tired groove walls?

The volume rate of removal of stylus material per unit distance of travel along the groove is given, with disarming simplicity, by eq. 15. It is usually more convenient, however, to measure stylus wear in terms of the diameter of the "flat" that gradually appears on the flanks of the spherical tip. This conversion can be made readily by noting that

$$V = \frac{\pi}{64}\frac{D^4}{R}\left(1 + \frac{D^2}{12R^2} + \dots\right) \doteq \frac{\pi}{64}\frac{D^4}{R} \tag{16}$$

When the approximate form of eq. 16 is introduced in eq. 15, the controlling relation for stylus wear can be written in the form

[11] A. J. W. Moore, "Deformation of Metals in Static and in Sliding Contact," *Proc. Roy. Soc.* (*London*) **A195**, 231-244 (1948).

[12] R. Holm, *Electrical Contacts*, pp. 214-221, H. Geber, Stockholm, 1946; also "Hardness and Its Influence on Wear," pp. 317-329, in *Mechanical Wear*. (See footnote 10.)

[13] J. T. Burwell and C. D. Strang, "On the Empirical Law of Adhesive Wear," *J. Appl. Phys.*, **23**, 18–28 (1952).

$$\frac{0.049}{RZ}\frac{D^4}{L} = A_{re} \qquad (17)$$

The problem of analyzing stylus wear now becomes one of studying the behavior of the area of real contact A_{re} under various conditions of operation. So long as the deformation of the underlying record material supporting the asperities remains wholly elastic (as for the *A* and *B* traces of Fig. 10), we can infer from the remarks following eq. 14 that

$$A_{re} = W/3Y_0 \qquad \text{(elastic)} \qquad (18)$$

On the other hand, if the base material itself is stressed highly enough to flow plastically, the asperities will tend to be thrust into the base material; or, to put it another way, in the underlying medium becomes progressively more fully developed. It is to be noted that the apparent area of contact is itself directly proportional to the load in this case, since these are the conditions for which the mean pressure P_m remains essentially constant at the value $3Y_0$. A companion expression similar to eq. 18 can, therefore, be written as

$$A_{re} = 0.8\,A_{app} = 0.8\frac{W}{P_m} = 0.8\frac{W}{3Y_0} \qquad \text{(fully plastic)} \qquad (19)$$

The areas of contact, both real and apparent, cannot be described in such simple mathematical form for the transition condition that is not wholly elastic nor yet fully plastic. The course of variation of these areas can be deduced, however, from a study of Fig. 11, which shows the typical variation of mean pressure with applied load for two sets of circumstances.

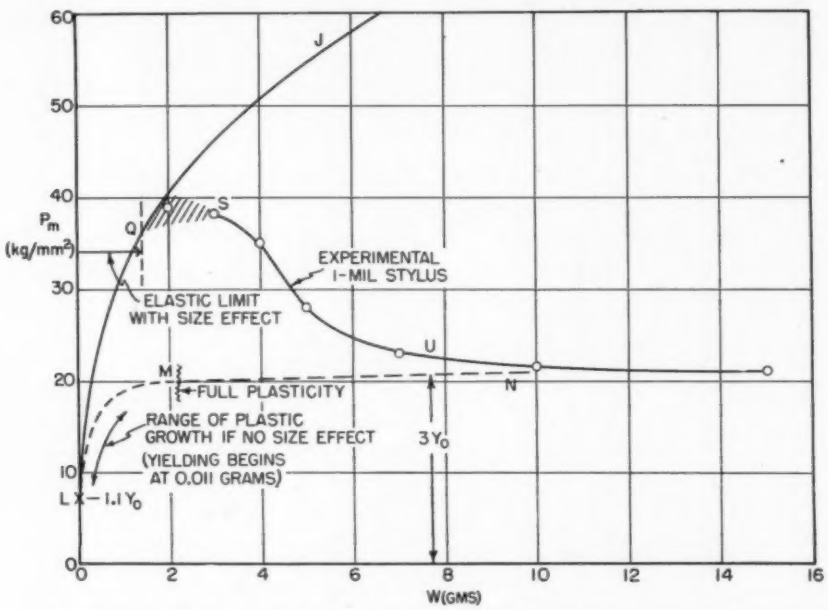

FIG. 11. The dashed curve *OLMN* shows the archetype behavior of P_m versus W for the relatively large spherical indenters used in hardness testing (*Tabor*[5]); the curve *OLQSU* shows how the size effect influences this behavior for a 1-mil stylus.

the underlying material will flow plastically until it engulfs the asperities and establishes real contact over nearly all the apparent surface of contact. An intermediate stage in the establishment of this situation is shown in the lower part of Fig. 9. Note, however, that the size effect (now working in reverse, as it were) prevents the spaces between the asperities from disappearing entirely (compare trace *C* of Fig. 10). It will be assumed, then, in the absence of more precise information, that the ratio of the real to the apparent area of contact will vary from about 0.5 to 0.8 as the plastic state

If it were possible for the deformations of the groove wall to remain completely elastic, P_m would follow the ⅓-power curve *OLQJ*. Plastic yielding always will begin at some point along this curve, however, and in the absence of any size effect—or what is equivalent, for a large-radius indenter, as in case *a* above—it will do so at *L*. It is of interest to note that the value of W at the onset of yielding is so small (only 11 milligrams for a 1-mil stylus!) that the "elastic" segment *OL* appears to be almost vertical when a linear scale is used for W.

As yielding begins, the P_m curve breaks away from the elastic curve along the dashed line *LM*, but full plasticity is not established until the load W has increased to about 100 to 200 times its value at the onset of yielding (a factor of 20 comes from the cube of 3/1.1, and the rest from the decreased slope of *LM*).[5] The apparent area of the surface of contact can then be found for each point along *OLMN*, merely by dividing W by P_m. The way this area varies with W is shown by the upper curve (correspondingly lettered) of Fig. 12.

An example of the profound influence of the size effect on the stylus-groove contact can now be exhibited by adding to Fig. 11 the experimental curve *QSU*, which is a replot of the indentation data of Fig. 2. The situation represented by this curve seems clearly to fall within case *b* discussed above, since the value of P_m at which yielding begins appears to have been raised by a factor of nearly 5. What is even more important, so far as wear and noise are concerned, such an enhancement of the yield value of P_m increases the bearing load that can be supported with full elasticity by the cube of the enhancement ratio (P'_m/P_m in Fig. 8a).

The apparent area of contact for points along *OLQSU* is now computed as before and the results are represented in Fig. 12 by the correspondingly lettered curve. Note that the apparent area follows the "elastic" ⅔-power curve *OLQJ* as far as *Q*, at which point yielding begins and the area curve breaks upward along the dashed line *QSU*. The area of real contact, whose delineation is the objective of this graphical maneuvering, can now be pinned down with the help of eqs. 18 and 19. For loads that do not transgress the elastic boundary at *Q*, the real area increases along the slowly rising straight line *OHP*, whose slope is the reciprocal of $3Y_\mu$. Note that this segment of the real-area curve does not depend at all on the apparent area of contact. Beyond the break in this curve at *P*, however, the apparent area takes over control in accordance with the remarks preceding eq. 19. Thus the *PSGU* portion of the real-area curve is to be constructed by assuming that the ratio of the real-to-apparent area will have reached the value 0.5 at *S*, and that this ratio increases smoothly to 0.8 at *U*.

The real-area curve of Fig. 12 can now be identified as the relative stylus wear rate (see eq. 15 or eq. 17). The existence of a sharp break in this curve at *P* suggests—in fact, it fairly shouts—that substantial reductions in the rate of stylus wear can be achieved by operating exclusively along the low-slope *HP* portion of such a rate curve. Thus, for example, the rate curve of Fig. 12 predicts that a reduction of the load from 4 grams to 2 grams would lower the wear rate by a factor of 14; that a change from 5 grams to 2 grams would yield a factor of 25; and that a change from 7 grams to 1 gram would reduce wear by a factor of 100. It must be quickly pointed out, however, that the wear reduction is strongly influenced by the micro-yield strength, and that these numerical estimates merely indicate the improvement to be expected *if* Y_μ has the value $20Y_0$ assumed in drawing Fig. 12.

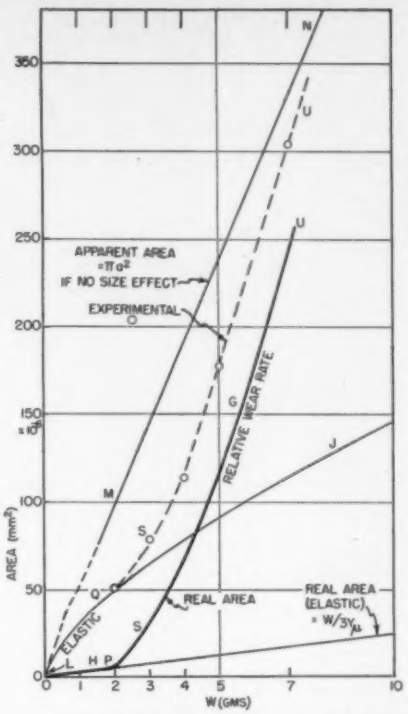

FIG. 12. Real and apparent areas of contact derived in part from the P_m versus W curves of Fig. 11, with corresponding curves similarly lettered. The heavy-line curve shows the variation of relative stylus wear rate with load.

It is fortunate that even though reliable estimates of the microyield strength are not yet available, the break point in the real-area curve can be located, at least with enough precision to furnish useful design guidance, by following the experimental and graphical routines described above. The inability to precalculate accurately the *amount* of wear-rate improvement need not, therefore, inhibit—and should not be allowed to delay—the redesign of conventional pickups for substantially extended stylus life.

A quantitative assessment of the exchange probability Z is needed if eqs. 15 and 17 are to be made numerically as well as functionally useful. Both Bauer[1] and Weiler[14] have reported stylus wear tests from which Z can be deduced. A novel consideration needs to be allowed for, however, in making use of their results. Neither of these experimenters

[14] Harold D. Weiler, *The Wear and Care of Records and Styli*, pp. 32, 43, Climax Publishing Company, New York, 1954.

attempted to measure the "flat" until it had attained a diameter of 0.75 mil; but such a flat already exceeds the diameter of the "elastic" circle of contact. As a matter of fact, as Bauer points out, it is unlikely that a so-called "flat" is really very flat until it does reach the stage at which its diameter is at least equal to that of the elastic circle of contact. In using these reported wear data, therefore, the apparent area of contact must be taken as that of the flat itself. The effective mean pressure will be lowered somewhat by this enhancement of the bearing area, but a few trial computations indicate that only a flat of intolerable size could lower the pressure enough to remit the condition of plasticity. As before, then, the real area will be controlled by the apparent area and will be given in this case by

$$A_{re} = 0.8\, A_{app} = 0.8\,\frac{\pi D^2}{4} \qquad (20)$$

When this equation is combined with eq. 19, the wear relation becomes

$$D^2 = 12.8\, ZRL, \qquad D > (6R\,W/E')^{1/3} \qquad (21)$$

Since this relation only holds *after* the flat has reached the indicated minimum size, it is the rate at which the flat is predicted to grow thereafter that must be used in coordinating experimental data. This is found by differentiating eq. 21 to give

$$\frac{\triangle D}{\triangle L} = 6.4\,\frac{RZ}{D} \qquad (22)$$

The exchange probability Z can now be evaluated by substituting the reported wear data in eq. 22. Weiler's wear rates are somewhat higher than Bauer's, but in conjunction they can be used to define a probable range of values for the exchange probability for sapphire and diamond as follows:

$$Z_{\text{sapphire}} = \begin{matrix} 0.24 \times 10^{-10}\ \text{(Bauer)} \\ 1.7 \times 10^{-10}\ \text{(Weiler)} \end{matrix} \qquad (23)$$

$$Z_{\text{diamond}} = 3.9 \times 10^{-12}\ \text{(Weiler)}$$

Relatively few numerical values of Z are available for comparison with these estimates. It is interesting, however, and perhaps useful, to notice that the Z-value for the harder of two materials in sliding contact appears to vary approximately as the inverse cube of the hardness number. No theoretical explanation of this relation can be offered. Neither can it be said with any certainty that such a relation would hold over a sufficiently wide range to allow the values of Z given by eq. 23 to be used as a basis for predicting *record* wear. Nevertheless, it can be expected that there will be some pertinent value of Z for the record material, since the exchange theory of rubbing wear advanced here can be applied equally well to the abrasion of either stylus or record material. In short, rubbing wear is always bilateral and mutual, and both stylus and record groove "grow old together," each wearing away at the rate corresponding to its own particle-exchange probability.

One further comment needs to be added concerning the interpretation of these exchange probabilities. It was tacitly assumed in defining Z that the probability of removing a single particle was not influenced by anything that might be happening to, or might already have happened to, any other particle. Such an assumption is probably justified for the lightly loaded condition in which the area of real contact is only a small fraction of the apparent area of contact. On the other hand, when the fully plastic condition prevails and the real area becomes nearly as large as the apparent area of contact, there may be literally no place for the abraded wear particles to hide. Wear particles may thus become trapped between the two surfaces, as illustrated diagrammatically in Fig. 9, where their abrasive and gouging action can serve to dislodge many more wear particles than would be expected on the basis of a constant exchange probability. When the rubbing orbit is a closed circuit, as in a journal bearing, this effect can cascade and precipitate seizure,[13] and even for the open orbits represented by a record groove, it can presumably explain Weiler's observation that wear particles themselves are important accelerants of wear. Whether large or small, however, the contribution that such interference makes to the wear rate will already have made itself felt in the wear tests relied on above in estimating Z. As a consequence, substantially smaller values of Z than those given by eq. 23 should probably be used in predicting wear rates for loadings that are light enough to confine operation to the *HP*, or elastic, portion of the wear-rate curve.

STATIC VERSUS DYNAMIC LOADING OF THE STYLUS CONTACT

It is a measure, perhaps, of progress in the phonograph arts that it is now taken for granted that proper tracking of a lateral-cut groove demands that the stylus be supported in continuous contact with both sidewalls without bottoming in the groove. Most pickups now in use can meet this requirement (at least until the stylus becomes badly worn), although as recently as fifteen years ago, when the basic requirements for proper tracking were first enunciated,[15] there were no pickups available that were free from the sin of bottoming in the groove both on account of stylus shape and because the bearing weights were always high enough to deform the groove walls until contact was established on the tip as well as on the flanks of the stylus. All the analysis presented above, however, has been couched in terms of the loading of a single stylus-groove contact, from

[15] J. A. Pierce and F. V. Hunt, "On Distortion in Sound Reproduction from Phonograph Records," *J. Acoust. Soc. Amer.*, **10**, 14–28 (1938); U. S. Pat. No. 2,239,717. (See footnote 2.)

which it follows that all the bearing loads mentioned must be multiplied by 1.4 when they are to be interpreted as representing the total weight carried by the stylus.

Another quantitative feature of the stylus-contact loading resides in the fact that it is the instantaneous or dynamic stylus force that controls the groove wall deformation, *not* alone the static or average value of the bearing load. The importance of this consideration in pickup design is paramount. Although the average of the instantaneous stylus force cannot exceed the static value, high momentary peak values of groove-wall reaction force can and do occur, both as a result of high peak factors in the recorded signal and as a consequence of the vertical motion required to "track" the pinch effect. The effect of these high momentary force reactions on stylus wear will *not* average out in a linear fashion owing to the sharp break in the slope of the wear-rate curve at *P*. It follows that if the low wear rates promised by the *HP* portion of the rate curve are to be achieved in practice, the peak loading must not exceed the value corresponding to the knee of the curve. This is equivalent to saying that the pickup stylus must be able to follow both the lateral groove modulation *and* the vertical pinch-effect excursions without arousing even momentary peak values of groove-wall reaction in excess of those imposed by the static bearing load.

It is easy to show that peak stylus accelerations of the order of magnitude 1000"*g*" may be demanded in both horizontal and vertical directions for proper tracking at typical recorded levels. This numerical boundary condition, in conjunction with the foregoing, leads to the convenient specification that the equivalent vibratory mass of the stylus measured in milligrams should be no larger than the static value of the bearing load in grams. Moreover, it is not sufficient merely to provide "compliance" for the vertical motion of the stylus demanded by the pinch effect; it is also necessary that the equivalent vibratory mass of the stylus for vertical motion be kept almost as low as for lateral, since the vertical acceleration demand becomes nearly as large as the lateral for high-level, high-frequency groove modulation.

SURFACE NOISE

Two, at least, of the factors that contribute to "surface noise" have their origin in the playback process itself. One stems from the stick-slip nature of sliding friction, the other from the microscale intermittency of plastic flow. To single these out for discussion is not, of course, to deny the importance of such troublesome sources of noise as dust lodged in the record groove, thermal agitation of the cutting stylus, lead-screw vibration transmitted to the cutting head, turntable bearing noise, and so on. The control or elimination of these troubles must be accomplished *before* playback, however, since the pickup, if it is to be honest, must reproduce these unwanted groove modulations just as faithfully as it does the signal modulation.

Vibration of the pickup stylus induced by frictional drag *ought* not to be transduced into an electrical output signal, but few pickups are proof against this kind of vibrational stimulus to an adequate degree. The effective coefficient of friction for a sapphire stylus on unfilled vinylite, at conventional loadings, may lie in the range between 0.2 and 0.5, and hence very small departures due to tangency and other alignment errors can produce lateral force components that are far from negligible. According to modern theories, the tangential force of friction has its origin in the shearing stresses required to break the bonds of adhesion established across the interfacial areas of real contact. These bonds can sometimes be as strong as the cohesive forces that hold the material itself together, as in the contact of similar dry, clean metals; or they may be extremely weak, as in the case of contact between Teflon and almost anything else. The adhesion can never vanish entirely, however, even for materials as dissimilar as sapphire and vinylite, since there is bound to be some interpenetration, on the atomic scale at least, in the regions of real contact.

One consequence of the foregoing is that the contribution of each local true-contact area to the friction force will always be of the stick-slip variety. That is to say, each asperity will first "stick," then progressively experience elastic deformation in shear produced by the gross sliding motion, until finally the shear stress becomes high enough to produce another "slip" either by rupturing the asperity or by causing the adhering surfaces to separate. The total force of friction will thus represent a statistical summation of the stick-slip contributions from all the local areas of real contact. This inherent "graininess" of the force of friction is closely analogous to the "graininess" of the electron current in temperature-limited thermionic emission. In view of this analogy, the surface noise arising from this cause might be called a frictional "shot effect"; and like the electronic shot effect, it will have a "white," or uniform, spectral distribution whose spectrum level will be directly proportional to the total "current"—in this case the total number of "slips" per second. It follows that this component of noise will be abated by anything that reduces the net frictional drag, such as lubrication(!) or a choice of materials having lower interfacial adhesion. Who will be the first to produce a pressing (or a stylus) with a Teflon surface? More immediate relief from this cause of surface noise is to be found, however, in a mere reduction of the stylus loading. The coefficient of friction appears to drop to substantially lower values when the medium underlying the surface asperities is not stressed beyond its elastic limit, and this effect combines with the reduced normal force to yield a compound reduction of the tangential force of friction.

What is probably the most important residual factor contributing to surface noise is that originating in the mechanism of plastic yielding. Even materials as nearly amorphous as record plastics must be conceived to "flow" by a process involving the slipping of molecular aggregates from one position of equilibrium with their neighbors to another. In elastic deformation, to point up the contrast, no atom is strained to move beyond the continuing influence of its neighbors and each returns to its original equilibrium site when external stress is removed; in fact such complete recovery is the essence of *elastic* strain. At the atomic, molecular, or macromolecular size level, however, the mechanism of plastic yielding takes the form of a volumetric version of stick-slip behavior, and must be regarded as inherently discontinuous in microscopic detail even though it appears in statistical summation to be continuous. A homely illustration of this type of behavior is available to anyone who can recall how it feels to thrust a stick slowly into wet sand—a revealing analogy suggested to me in 1941 by R. M. Morris during our naive discussion of what we promptly dubbed the "crunch-crunch theory of surface noise."

A good bit of study has been devoted to the slip phenomena occurring in metals but, as usual, information bearing on phonographic materials is conspicuously missing. As a matter of fact, it may well be that the techniques of phonograph playback applied to metal molds made of materials that have already been studied theoretically would yield new and useful grist for the solid-state physicists' mill. Pending further enlightenment from that quarter, however, it seems safe to presume that the energy of the noise arising from this source must vary in some way with the cohesive forces of the record material (its hardness, perhaps?) and with the total volume of material deformed plastically by the stylus. Moreover, two components of this "crunch" noise can be identified: one that varies with the static loading of the stylus and is always present even in the absence of groove modulation, and one that corresponds to the periodic plastic flow induced by the dynamic force reactions arising from groove modulation. The latter component constitutes a modulation noise, or "noise behind the signal," of the type whose elimination yields a welcome improvement in the so-called "cleanness" of reproduction. Fortunately, both of these noise components can be eliminated completely by the straightforward expedient of avoiding the conditions of static and dynamic stylus loading that induce plastic flow.

CONCLUSIONS

The simple moral of this tale is that plastic yielding of the record material under the conventionally loaded stylus is primarily responsible for a deplorably high rate of stylus wear and record wear, and for at least three identifiable components of playback surface noise. Quantitative estimates of shaky precision but undeniable trend suggest that a five-to-one reduction of pickup bearing weights and a ten-to-one reduction of dynamic stylus loading will yield a relatively spectacular extension of both stylus life and record life, and a substantial reduction of surface noise; and that these benefits will yield a secondary improvement of average distortion levels that now soar due to the complacent retention in service of styli long since worn flat. Scattered, but reassuring, experimental evidence confirms the feasibility of achieving these predicted improvements.

ACKNOWLEDGMENTS

I have already mentioned my thanks to Dr. T. J. Schultz for the careful indentation measurements that furnish a numerical anchor for some of these speculations. I am also indebted to Dr. J. T. Burwell for incisive criticism of my analysis of elastic-plastic instability and to Professors H. Brooks, M. C. Shaw and B. Chalmers for helpful discussions and much background information concerning related aspects of the physics of metals. Finally, I acknowledge fondly the continuing connivance of my phonographic colleague, J. A. Pierce.

Record Quality and Its Relation to Manufacturing*

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THE GOAL of record manufacturing is a record which reproduces in microscopic detail the surface geometry of the disk cut by the recording engineer. Anything which the manufacturing operations add or subtract can result only in deterioration of the information on the record, e.g., the addition of noise as ticks and "grit" or as distortion. We do not at this moment foresee the day when manufacturing will be asked to improve on the recording engineer's handiwork. We have our hands full achieving present goals.

The past decade has seen advances in the engineering aspects of recording and playback systems. These improvements have served not only to put more information on the record, in the form of wider frequency range, but to secure this wider frequency range on records having narrower and more closely spaced grooves. Improvements in manufacturing processes have been necessary in order to make this added information available on records delivered to the ultimate consumer. It is our purpose to review some of the changes in the manufacture of RCA Victor records. The changes reviewed will be those which have been major factors in narrowing the gap between the recording process and the final record.

Superficially, the manufacturing process has remained the same. The recorded disk is metalized to make the surface conductive, after which a negative master is made by electroforming. To obtain protection and a number of metal parts, a positive is made from this master by electroforming to obtain a mold or "mother." This mold serves to generate pressing masters or "stampers" which are used in plastic molding presses that were employed many years ago. Figure 1 illustrates the essential elements of the process. Consequently, it was necessary to investigate the matter in some detail to get at the improvements, just as we have to go beyond the four wheels of the automobile and water-cooled four-cycle internal-combustion engine to establish the differences between the latest and previous automobiles.

It should be apparent that the key to the problem is the stamper. If a stamper surface reproduces the surface of the recording in microscopic detail, a molded record surface reproducing this detail is possible. The first step, therefore, was a review of the matrix operations with the object of eliminating any operation which resulted in deterioration of the information on the recorded surface.

In the program which was initiated more than ten years ago it was recognized that mechanical work on the matrix surface, whether called polishing or abrasive cleaning, could result only in deterioration. Although tolerable on 78-rpm filled records, tested as they were on then current commercial equipment, it was recognized that such operations could not be tolerated on either fine-groove records or equipment of wide frequency range.

However, it was soon found that polishing could not be eliminated by fiat. The cure was worse than the disease. The first logical step was to substitute electrochemical and chemical methods of cleaning for the polishing and hand scrubbing which was then common. It was found that the resultant parts, molds or records, were so full of ticks that the sound was certainly not improved on. Many changes were still needed. Of these changes, three were chiefly responsible for making the elimination of polishing and the substitution of nonmechanical methods of cleaning practical.

These three major improvements were: the substitution of lacquer disks for wax, the control of stress in nickel solutions, and the control of impurities in the nickel solutions. The last two are not entirely independent. However, each contributed its major share to quality improvement, independent of the other.

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† Manager of the Chemical and Physical Laboratory.

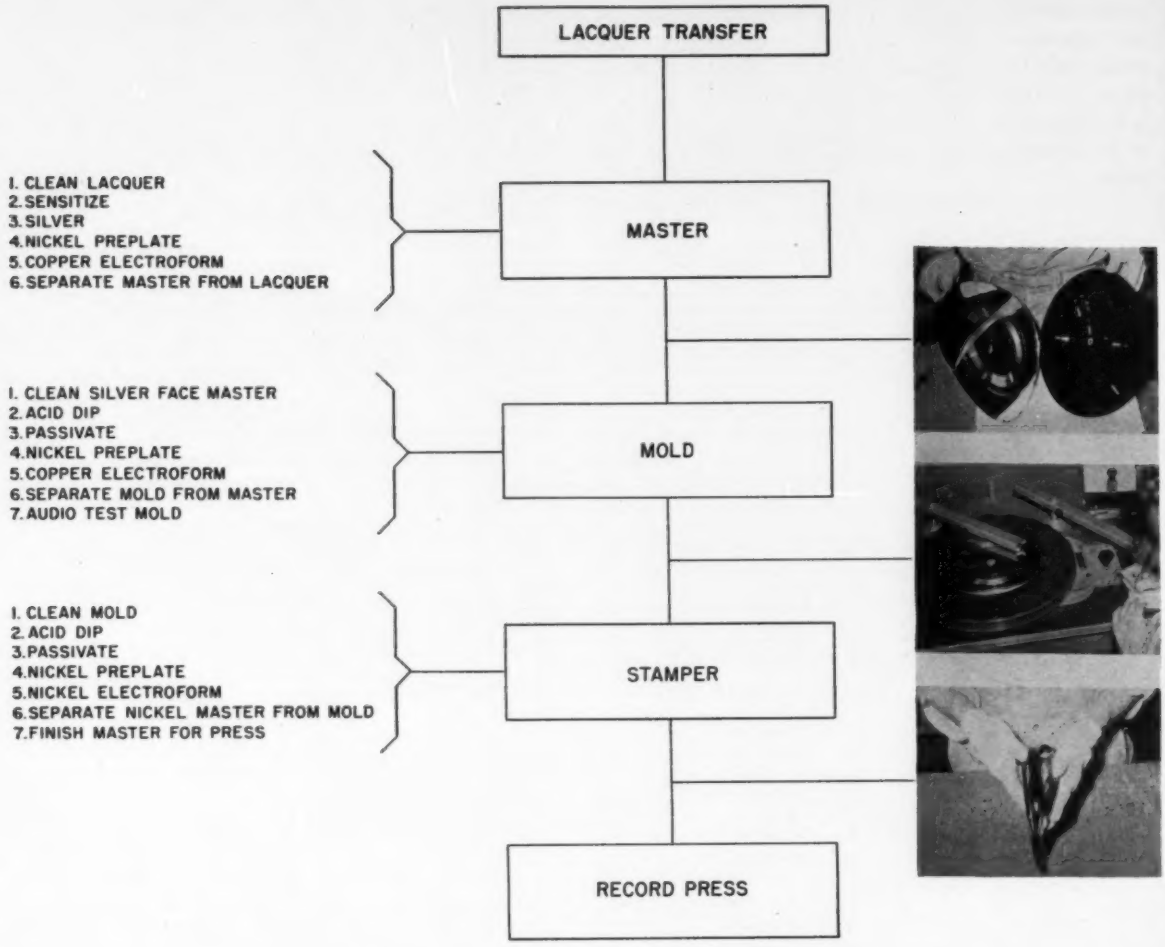

FIG. 1. Sequence of operations for disk record manufacturing.

For many years, the original recordings were made on a wax composition based on Montan wax. After the recording was made, the surface of the wax was made conductive by brushing graphite into the surface. The limitations of the process are apparent. First, the grain size of the graphite particles led to an inherent surface roughness and consequent surface noise. The danger of groove change by the brushing was always present. The results obtained depended on the skill of the operator.

In the late 1930's, Bell System engineers introduced gold sputtering. This step eliminated the crystallinity of the graphite particles and the dangers of brushing the grooves, but unfortunately other deficiencies appeared. These deficiencies were particularly noticeable with fine-groove work. They showed as small defects in the grooves which on playback manifested themselves as ear-splitting ticks. Furthermore, surface noise was not consistent. Considerable effort was expended in trying to eliminate the occurrence of these defects, but direct proof of their cause was never determined. Some conclusions were reached, however, among them the following:

1. The wax surface was not as smooth as recording engineers thought it to be. In some formulation work, for example, a correlation was found between graininess of the wax surface before cutting and surface noise of the grooves. This surface roughness is apparent in Figs. 2 and 3.

2. The wax formulation was not homogeneous. As a result, under the vacuum and heat of sputtering, localized outgassing occurred which prevented or reduced gold deposition at these spots. When the operation was viewed through

a glass porthole, this phenomenon became evident as localized high-density spots in the glow discharge. Part of the trouble was heat. Measurements of surface temperatures during a normal sputtering cycle showed that the wax surface temperature rose to 180 to 210°F with normal cooling of the mounting plate. Figures 4 and 5 illustrate these points.

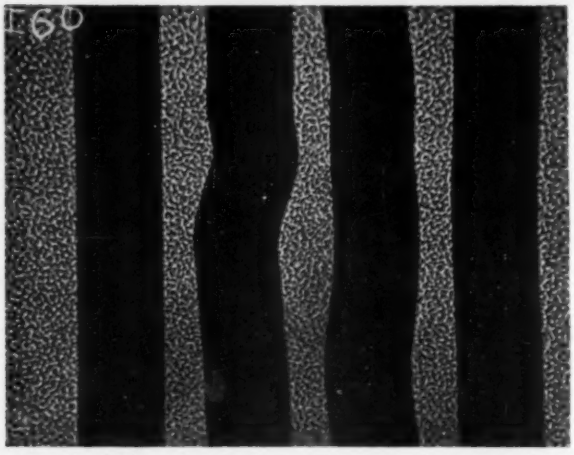

FIG. 2. Gold-sputtered wax recording, focused on land at 250 diameters magnification.

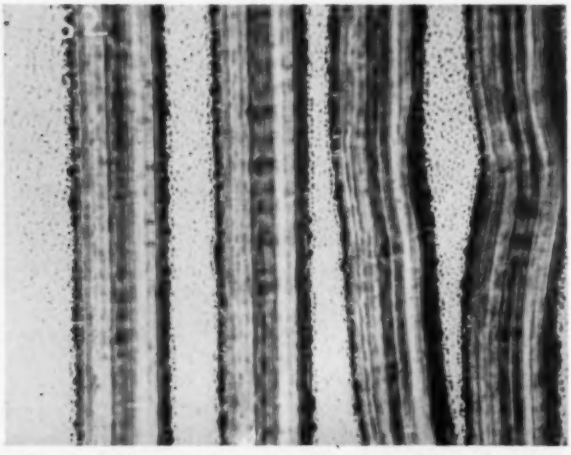

FIG. 3. Gold-sputtered wax recording, focused near the middle of the groove wall at 250 diameters magnification.

Concomitant with the development of gold sputtering of wax, the recording and processing of lacquer discs was being investigated. Lacquer discs have their deficiencies with respect to recording. The rheological properties are such that the groove does not cut smoothly. To compensate for this,

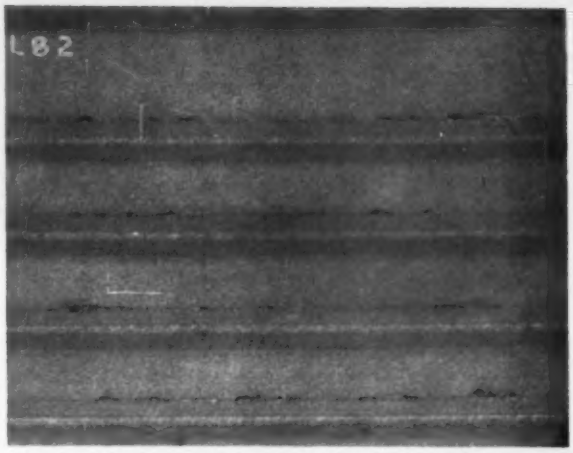

FIG. 4. Copper-preplated gold-sputtered wax, at 50 diameters. Black areas show pores in the copper.

burnishing facets[1] which polish the groove wall are used. These have the disadvantage of producing cross-modulation which shows up particularly as echo. The effect of the burnishing facets also varies with the angle the groove wall makes with the tangent to the radius. Both of these effects, cross-modulation and a rough side wall at sharp wave fronts, are shown in Fig. 6. Another disadvantage is the difference between input level and recorded level, which is a function of linear groove velocity and frequency. Even with these limitations, however, it was found that the lacquer disk resulted in a better record. More consistent manufacturing

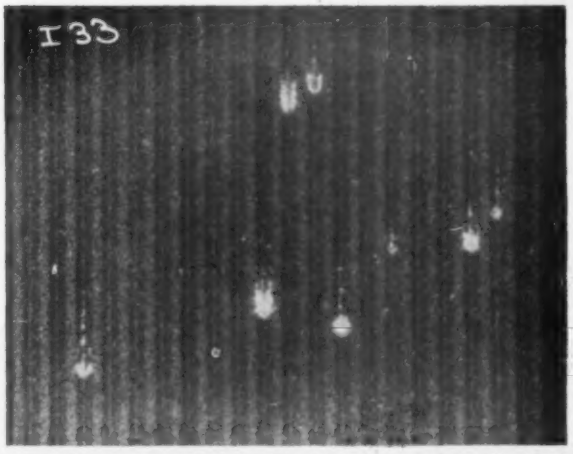

FIG. 5. Copper-preplated gold-sputtered wax, at 50 diameters. Light areas show pores in the copper.

[1] I. L. Capps, "The Design of a New Lacquer Recording Stylus," *Audio Eng.*, 32, 18 (January, 1948).

results were obtained with proper metalizing and preplating. The surface noise was less variable, and there were fewer surface defects resulting in ticks, "grit," and "swish." The use of a heated stylus for lacquer recording has minimized the difficulties of cutting lacquers.

Metalizing is extremely important. Any discontinuities in the metal film will not cover over immediately in preplating. If small enough, the metal deposit will bridge over the gap. This bridge represents a pit in the master surface and an unwanted bump in the mold surface. Thus, it will result in a tick if it occurs in a groove. Fortunately, it is comparatively easy to check for adequate metalizing on lacquers. The mirror film can be examined visually under a magnifying glass. Any small discontinuities are easily visible as black spots.

Wet silvering methods are preferred for metalizing lacquers. The high vacuum and heat involved in sputtering was found to be incompatible with the relative volatility of residual solvent and plasticizer in the lacquer film. The method consists in cleaning the lacquer in trisodium phosphate solution or similar mild detergent solution for approximately 5 minutes. Strong cleaners, acids, or high temperatures tend to "dry out" the lacquer, roughen the surface, and thus raise the surface noise. Figure 7 illustrates, for example, the effect of temperature of cleaning on surface noise.

After being cleaned, the lacquer is spray-rinsed thoroughly and immersed in a stannous chloride sensitizer solution. The stannous chloride probably seeds the surface with an adsorbed layer of tin ions, which serve as nuclei for silver crystallization. The lacquer surface must then be rinsed thoroughly to remove excess chloride. The rinse water should be low in chlorides. We prefer to use a strong spray with the lacquer rotating under the spray and finish with a deionized water rinse. Any free chlorides in the water film will

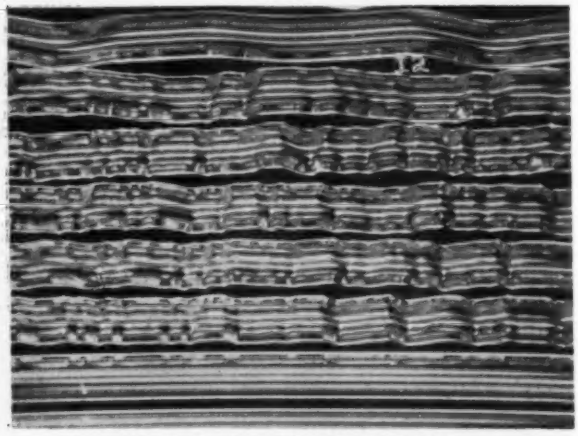

Fig. 6. Lacquer disk recording (1948).

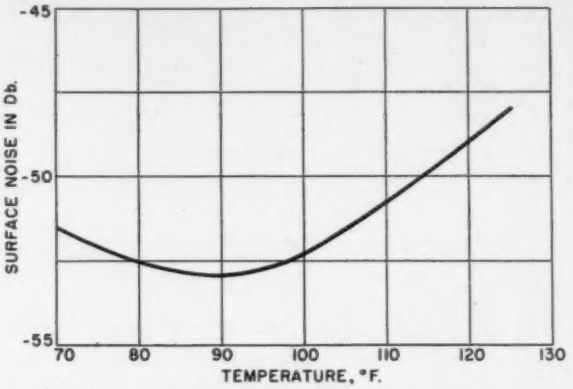

Fig. 7. Effect of cleaner temperature on the surface noise of molds.

cause the silver to be nonuniform, showing up as clouds or stains. After the thorough rinse the lacquer is put in a flat, round tray and clear ammoniacal silver nitrate solution and reducer solution are poured over it. The tray is rocked and rotated until silvering is complete. For tray silvering, a slow deposition rate is desirable. Consequently, chilled solutions and a slow reducer such as dextrose are used. Spray silvering with a two-nozzle gun, one nozzle for the silver solution and one for reducer, is also used. Here, the two sprays converge a short distance from the nozzle, and a fast reducer such as formaldehyde is necessary. After the silvering process, a strong water spray is desirable (replacing a camel's hair brush) to remove any coarse, loose particles of silver which would cause an unsound subsequent electrodeposit.

We have found the silvering operation itself to be relatively noncritical. Preparation of the lacquer, particularly the sensitizing operation, is most important. If, for example, a small air bubble persists in the groove during sensitizing, that spot will not cover during silvering. The sensitizing must be given enough time. If the surface is not sensitized sufficiently, silver may form but it will be easily washed off the lacquer surface. If the lacquer is oversensitized, the silver will stick tightly enough to damage the lacquer surface when the master is separated.

The silvering operation involves a number of steps. Between each step the lacquer must be handled. To reduce the hazards of damaging the lacquer surface and to ensure better timing control of the different phases of the operation, an automatic silvering machine was developed. The machine has spray guns for sensitizer solution, water rinsing, and the silver and reducer spray guns. The lacquer is put in the chamber (Fig. 8) on a turntable. A sequence timer then takes over and starts and stops the operations: rinse, sensitize, rinse, silver, and rinse.

Obviously, metalizing is the first step in the production of a negative replica of the recorded surface. The next is to build a sound structure on the silver, which in the master becomes the supporting structure of the silver surface. Any porosity or coarseness of structure will manifest itself in surface noise, "grit," or ticks. The effect of porosity is evident. In the case of a large-grained structure, the effect is not so apparent. An electrodeposit will begin with a crystal structure duplicating the structure on which it is being formed, in this case the metalized film. This initial layer is reported to be 1000 to 2000 Ångströms thick[2]

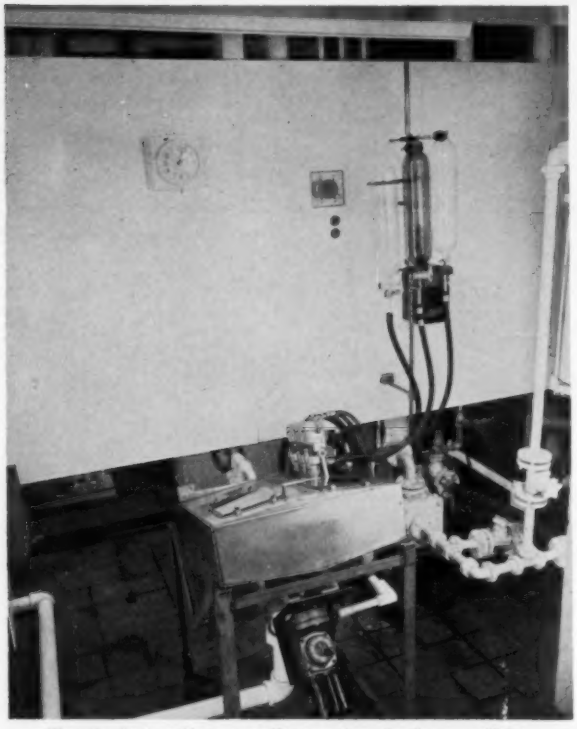

FIG. 8. Automatic spray silver system for lacquer disks.

(3 to 6 $\times$ 10^{-5} in.). Only after this initial layer is deposited does the crystal structure become characteristic of the solution and deposition conditions. However, apparently a coarse-grained structure produces enough localized stresses to impart a roughness to the surface which results in higher surface noise. The solution should, therefore, inherently deposit a fine-grained metal structure to support the silver film.

The initial layer of deposit must spread uniformly over the surface. Where lacquers are concerned, we are aided by the fact that the silver deposits are heavier than gold-sputtered deposits. For example, the best gold sputtering we could do resulted in a resistance of 6 ohms across a 12-in. disk, whereas silver will have a resistance of 2 ohms or less. The thicker film permits the use of higher currents with faster and more uniform coverage.

The requirement of a fine-grained deposit is usually contradictory to that of a good spreading deposit. In acid copper, for example, addition agents are used to obtain a fine crystal structure. These are conceived as interfering physically with crystal growth by adsorption or codeposition. Thus, they tend to interfere with the spreading of the deposit which, on the thin, comparatively high-resistance metalized films, tends initially toward lateral growth. To get good results from copper, a low-temperature (75 to 80°F) purified solution is needed.

With the development of a low-stress nickel solution of low impurity, it was found that nickel produced more dependable results than copper for the initial plating. For example, on tests of copper against nickel with six bands on twenty-five lacquers in each group, molds made from nickel-preplated silvered lacquers had an average surface noise of −54.6 db with a standard deviation of 2.32 db, compared with −50.5 db, 2.29 db standard deviation, for copper preplate. Temperature is important in obtaining best results. Control at 95°F gives best results for lacquer preplating with our nickel solution.

As implied in the above remarks, stress and impurity control are important in the nickel solution, particularly in the Watts type of solution which we use. A normal nickel deposit is stressed in such a way that the edges of the deposit tend to curl away from the starting surface. Obviously, this cannot be tolerated since, with lacquer, the silver is attached by only the most tenuous of forces.

Stress control of the nickel is also important in metal-to-metal duplication, e.g., making a mold from a master or a master from a mold. In the past it was customary to depend on a small amount of adhesion to keep the nickel in place to overcome the inherent nickel stress. If there was no adhesion, parts would split open in the tank and be ruined. If the adhesion was too good, the result might be a master and a mold surface stuck together. The ideal, as expressed by an old-time record foreman, was a squeal as parts were separated, just enough pin-point adhesion to keep things in place. This rupture of pin points roughened the surface sufficiently to increase the surface noise. The cleaning and passivating procedure was obviously very critical, and instructions and traditions were more representative of a voodoo ritual than a manufacturing operation. We can laugh now, but when a load of parts comes out of a tank after 8 hours or so and you find you can get only half of them

[2] G. T. Finch, H. Wilman, and L. Yang, "Crystal Growth at the Cathode," *Discussions Faraday Soc.*, No. 1, p. 144 (1947).

apart, you begin to wonder whether that extra wrist motion isn't necessary.

By tackling the problem at its source, the inherent stress of the nickel deposit, it was found that all the other problems disappeared. The passivating procedure is now drastic enough to ensure no adhesion and, consequently, we now find no noise increase in the music grooves through duplication. This is contrary to popular belief, we know.

In our first work in controlling stress we used the bow of an all-nickel part 0.010 in. thick as an indication of stress. With the development of the spiral contractometer,[3] it became possible to measure the stress. Duplicating solutions are now controlled at 10,000 to 15,000 psi stress. Lacquer preplating solutions are controlled at 1000 to 6000 psi stress. These values are obtained by means of addition agents.

Control of impurities in the nickel solution has been mentioned as important. Copper and iron are particularly harmful, not because they are the only possible deleterious impurities but because they happen to be present. Parts sometimes come off a rack, or nuts and bolts may get into the tanks. These are the obvious sources of impurities. What is commonly overlooked is that the purest form of commercial nickel anodes contains from five to ten times the proportion of these elements to nickel as is desired in the solution.

The effect of these two impurities is twofold. First, they interfere with covering; low spots, such as grooves in molds or "lands" in masters, tend to receive little plating. Second, these impurities tend to make the deposit more porous and brittle. As indicated previously, the sphere of influence of crystal interference is much larger than one would expect. The result is felt on the surface and shows up as a measurable increase in surface noise. Figure 9 shows how this effect can be seen. Heavy deposits over 0.005 in. thick tend to be rough.

In addition, copper and iron make the deposit more highly stressed. With normal equilibrium between anode and solution composition, for example, a stress value for nickel deposits from a Watts solution will average around 22,000 psi. With partial purification, or, more accurately, with present equipment, values between 15,000 and 20,000 psi are obtained. With more recent equipment designed to maintain the purest possible solution, we have achieved levels between 12,000 and 15,000 psi tensile stress without addition agents.

How are the impurities maintained at a low level? The principle of continuous dummying at low-current density is employed.[4] Solution is pumped from the plating tank through a purifying tank, then through a heat exchanger and filter which removes suspended particles, and then back to the plating tank. In the old design, gravity was depended on to settle the solution from the anodes, which has a higher specific gravity, to the bottom of the tank. Therefore, solution from the filter was pumped in at the top of the tank and the outlet was at the bottom. The heating of the solution with outside heat exchangers tends to assist in this downward flow of dirty solution.

Filtration is important. Suspended particles cause roughness which produce enough surface irregularities to raise the surface noise and cause ticks. In decorative plating, filtration equivalent to one turnover of the tank capacity in 2 to 3 hours is considered good practice. Faced with a more critical operation, we turn over the solution two to four times an hour.

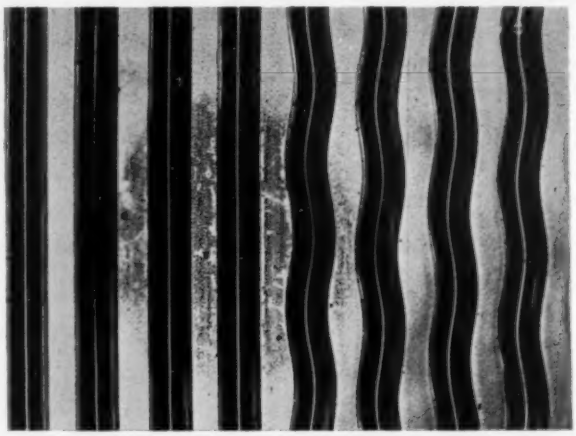

FIG. 9. Surface stain typical of duplication from an impure solution, at 50 diameters.

Newer equipment, presently being installed in one of the plants and designed after more than two years of testing in our laboratories, keeps impurities at the still lower levels. This design is the so-called diaphragm tank[5] in which the cathode solution is separated from the anode solution by a cloth diaphragm. Solution is pumped from the anode compartment through the purifying tank, heat exchanger, and filter, and then back into the cathode compartment. Flow from the cathode compartment to the anode compartment is by gravity through the cloth diaphragm. The trick is to choose a weave porous enough to maintain a difference in level between the two compartments of 1 to 2 in. This

[3] A. Brenner and S. Senderoff, "A Spiral Contractometer for Measuring Stress in Electrodeposits," *Proc. 35th Ann. Conv. Amer. Electroplaters' Soc.*, p. 53 (1948).

[4] B. C. Case, "Modern Applications of Electroplating Solution Purification," *Proc. 34th Ann. Conv. Amer. Electroplaters' Soc.*, p. 228 (1947).

[5] R. H. McCahan, C. E. MacKinnon, and D. A. Swalheim, "Diaphragm Tanks to Eliminate Roughness in Copper Plating," *Proc. 35th Ann. Conv. Amer. Electroplaters' Soc.*, p. 203 (1948).

design physically keeps the less pure solution from the anodes from mixing with the purified and filtered solution in the cathode compartment.

Now it is time to re-examine polishing. As long as various steps in matrix manufacturing contributed to a comparatively noisy surface, polishing was necessary to cover up defects. It is apparent that, if it can smooth over defects in the surface, it can smooth down some of the modulation in the grooves. High frequencies are especially susceptible (Fig. 10). The intermodulation tests made by Roys[6] show another manifestation of the ill effects of severe polishing. Figure 11, a microphotograph taken 8 years ago of some stampers rejected for "distortion," shows an extreme case. On the side walls, modulation appears which fades out at the top and bottom of the groove.

Polishing was a cumulative process. Because of the defects in the gold surface, the gold-faced master had to be polished. Then, to get a uniform surface, the surface was face-plated with a thin layer of nickel, which was again polished. This nickel surface was duplicated to make a mold, and the mold surface was again polished. After every stamper the mold was polished as well as the stamper. It was, therefore, not surprising, that, with every part made, further deterioration occurred. The common conception that, the closer the stamper was to the master, the more faithful was the reproduction of the record was true. Today this need not be true. In fact, we have made tests with present methods of matrix manufacture of as many as eight generations with no loss in frequency response and a negligible increase (1 to 2 db) in surface noise between the original mold and the eighth descendant of that mold.

Another common misconception is that the first pressing from a set of stampers is better than subsequent pressings. This may have been true with 78 rpm records where an abrasive filler is used in the plastic. With present unfilled plastics, wear of stampers is not a problem. No difference in frequency response or noise can be detected between the first and the thousandth record from a set of stampers.

It should be apparent that to cover the whole story of manufacturing changes in the past ten years would require considerable space and time. However, in this brief review,

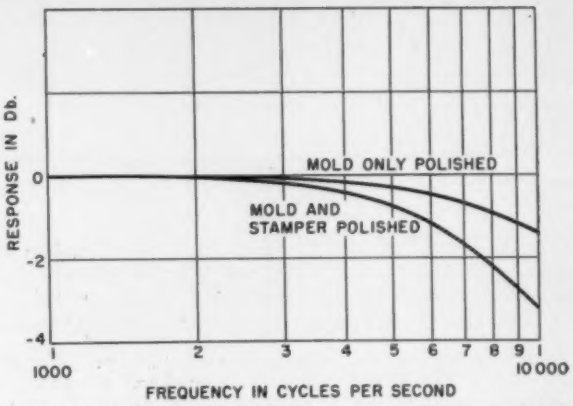

Fig. 10. Frequency response of records made from polished matrices.

the key developments in reducing the spread between the recording process and the record ultimately delivered to the consumer have been presented. Obviously, these developments are not the work of any single individual or group, but represent contributions from the recording and manufacturing personnel as well as workers in development engineering, all working toward the goal of giving the record buyer better reproduction and more music for his money.

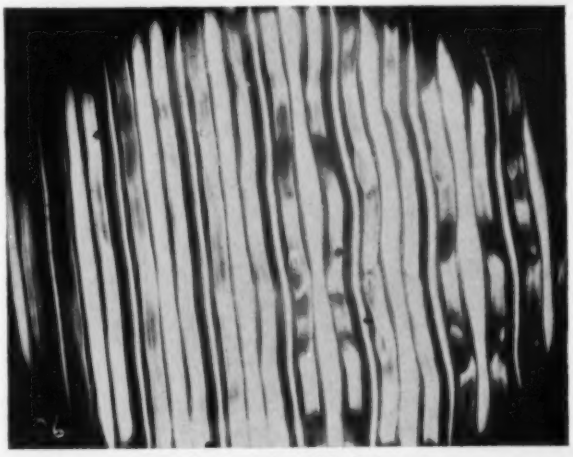

Fig. 11. Severely polished stamper.

[6] H. E. Roys, "Intermodulation Distortion Analysis as Applied to Disk Recording and Reproducing Equipment," *Proc. IRE*, 35, 1151 (1947).

Frequency-Modulation Noise in Magnetic Recording*

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Certain noise effects associated with high-frequency recorded signals are attributable to rapid fluctuations in the speed of the magnetic tape as it passes over the recording heads. The high-frequency tape flutter may be caused by resonant longitudinal vibrations which are excited by random frictional forces. The flutter rate can be determined theoretically from a consideration of the mechanical properties of magnetic tape, and the calculations verified by actual measurement with a frequency discriminator and spectrum analyzer.

WOW AND FLUTTER effects in magnetic recording have already been extensively investigated, but in most cases these studies have been limited to low flutter rates, usually below 100 cps. From the work of investigators in the instrumentation recording field, spontaneous frequency modulations at rates upward of several kilocycles are known to exist in magnetic tape systems. It has been found that under certain conditions these frequency modulations can cause audible noise effects not unlike the "modulation noise" associated with fluctuations in signal amplitude. Therefore, it would seem that a study of high-frequency tape flutter and its effects in recordings would be of interest to audio engineers.

The basic problems in frequency modulation are, of course, mechanical ones associated with the motion of the tape over the recording heads. A continuous spectrum of such mechanical disturbances can be discerned, extending from extremely long-term variations caused, for instance, by line voltage changes, through the midrange disturbances associated with drive eccentricities, to very short period phenomena. In this last category, the motion disturbances originate primarily in the tape itself, although the machine also plays an important subsidiary role, as will be pointed out later.

A convenient method of investigating very rapid frequency modulations is that of recording pure tones on the recording system under test and detecting the excursions of the reproduced signal by means of a frequency discriminator. However, in a discriminator of this type the band width of the demodulated FM signal is perhaps only 20% of the "carrier" frequency, and to cover the band of modulation frequencies desired a test signal of 30 kc was found necessary. This requirement dictated a tape speed of 30 ips, which is not strictly representative of current audio recorders. It can be demonstrated, however, that the principles established for the 30-ips system studied are generally valid for slower speed recorders. Figure 1 is a block diagram of the test recording and FM detection apparatus, including a panoramic type of spectrum analyzer for displaying the frequency components contained in the demodulated signal. The band width of the over-all system through the demodulation process is approximately 5 to 6 kc.

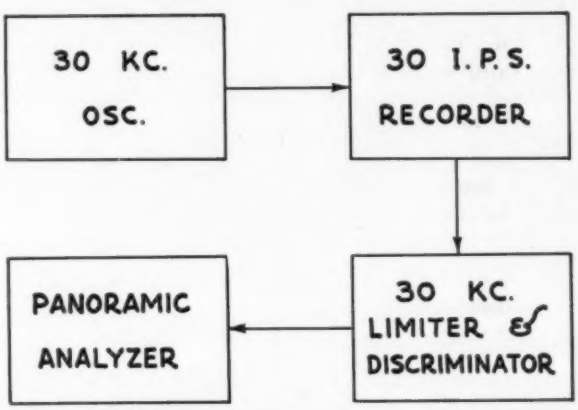

FIG. 1. Block diagram of the test apparatus used for measuring flutter components.

RESONANT TAPE VIBRATIONS

In the initial experiments with this FM detection system, a single dominant frequency of several kilocycles was noted in the demodulated FM signal from the test recorder. This led to an investigation of possible resonances in the tape

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† Assistant Technical Director, Magnetic Products Division.

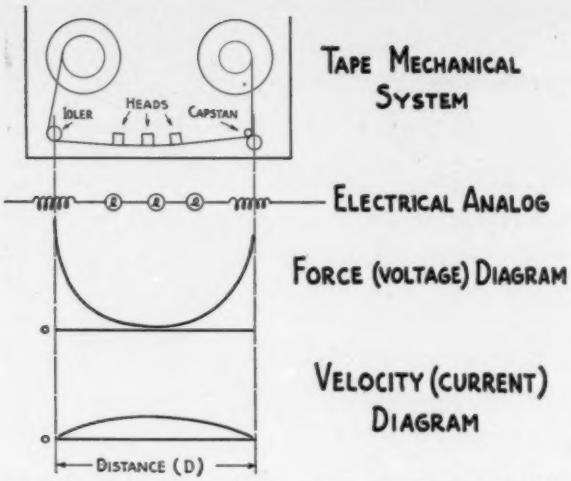

FIG. 2. Layout of a typical tape drive mechanism (top) and its electrical analog for the analysis of vibration effects. Typical force (voltage) and velocity (current) distributions are shown below.

itself, and from the nature of the experimental results a longitudinal vibration was suspected.

The complete solution of the equations for longitudinal wave motion in the recording tape is rather difficult and need not concern us here. However, it has been established[1] that the velocity of propagation (V) in this mode is given by the expression $V = (E/\rho)^{1/2}$, where E is Young's modulus and ρ the density of the tape. It must be assumed that E and ρ are constant throughout the thickness of the tape and are invariant with frequency and strain. These conditions are not met exactly in practical tapes, but the errors introduced by this assumption are apparently quite small. It is interesting to note that the velocity of propagation is independent of tape thickness and tension.

With the foregoing information, it is now possible to construct an electrical analog of the recorder mechanical system (containing the tape and associated driving parts) so that the behavior of the system can be more easily understood. The particular machine chosen for this investigation has three recording heads interposed between the capstan drive and motion-stabilizing idler pulley as shown diagramatically at the top of Fig. 2. In other machines, the idler pulley may be omitted, in which case the supply reel contributes the motion-stabilizing effect in so far as high-frequency tape vibrations are concerned.

In our electrical analog (second diagram of Fig. 2) the tape is represented by a transmission line in which the current in the line and the voltage on the line represent the velocity of and the force in the tape, respectively. The capstan drive and idler pulley are replaced by large inductances (i.e., elements whose force is proportional to the rate of change of velocity) which at these high frequencies effectively decouple the tape span from external influences such as those arising in the supply and takeup reels. The frictional forces acting on the tape as it passes over the heads and guides are represented by zero-impedance voltage generators in series with the line, since ordinary frictional forces are independent of the velocity of the frictional contact. The instantaneous velocity along the tape (corresponding to current in the line) is, of course, the variable of interest, and the frequency of the recorded signal will be modulated by the combined velocity excursions existing at the recording head during recording and at the reproduce head during playback. The complete system analog then comprises an open-circuited transmission-line section, voltage-driven near its center.

If the losses in the hypothetical line are low, it is apparent that we are now dealing with a resonator, the principle mode of which corresponds to a standing-wave pattern of one-half wavelength on the line segment. Voltage (force) maxima will appear at the ends of the span and a current (velocity) maximum at the center, as shown in the bottom diagram of Fig. 2. The resonant frequency, f, is given by

$$f = \frac{V}{2D} = \frac{(E/\rho)^{1/2}}{2D}$$

where D is the distance between the idler pulley and the drive capstan. The constants E and ρ of a typical recording tape were determined by direct measurement to be $E = 3.85 \times 10^{10}$ dynes/cm^2 and $\rho = 1.43$ grams/cc. The velocity of propagation is then 1.64×10^5 cm/sec; the resonant frequency as a function of the tape span, D, is shown in Fig. 3. Also plotted in Fig. 3 are measured resonant frequencies corresponding to 7-, 12-, and 18.5-in. spans, showing excellent agreement between the theory and the experimental data.

The relatively high velocity of propagation of vibrations along the tape is ample justification for disregarding the constant tape-drive velocity when studying vibration effects. The constant drive velocity enters the picture only when the frictional forces which excite the resonant tape span are being considered. The friction between the tape and the head varies from point to point along the tape so that the reaction of the head on the tape may be thought of as composed of a constant force which contributes to the average tape tension and a variable force which acts as a "force generator" in the vibration sense. The force components occurring at rates which are near the resonant frequency of the tape span are greatly reinforced and account for the high amplitude of flutter (although still random in nature) noted at certain frequencies in the discriminator tests.

[1] R. J. Youngquist, "The Problem of Wow in a Magnetic Tape Drive," Thesis, University of Minnesota, 1952.

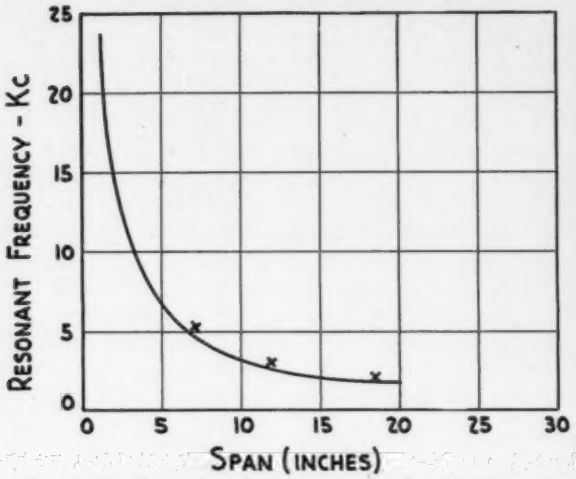

FIG. 3. Graph showing the resonant vibration frequency as a function of the free span for a typical recording tape having a Young's modulus (E) of 3.85×10^{10} dynes/cm^2 and a density of 1.43 grams/cc.

It is interesting to note that, since the frictional forces depend on the normal force, which in this case depends on the tape tension, the friction components may increase very rapidly with incoming tape tension, owing to the tension build-up across the heads. The effect of this "snubbing" action is apparent in Fig. 4A, which shows two FM spectra of the same system adjusted for 1.75 ounces of incoming tension in one case and 3.5 ounces in the other. The frequency of the FM "spike" is the same in each case, but the amplitude is more than doubled in the 3.5-ounce case. This change in tension was achieved quite easily by taking read-

FIG. 4. Photographs of flutter spectra obtained with the apparatus of Fig. 1.

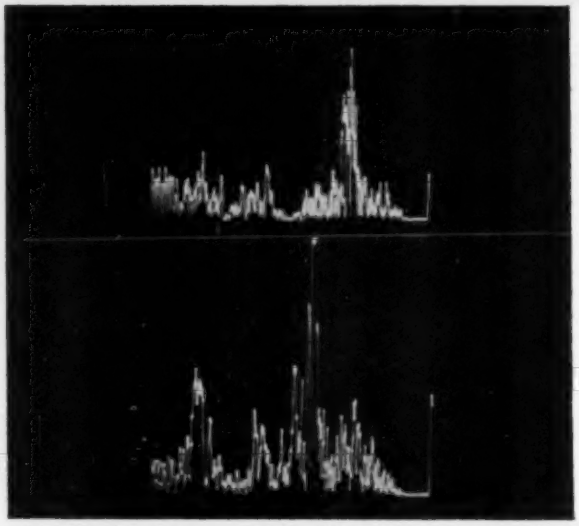

FIG. 4B. *Top*, tape span 12 in., flutter 0.4% peak to peak at 2700 cps. *Bottom*, tape span 18.5 in., flutter 0.6% peak to peak at 1800 cps (note second mode at 3600 cps).

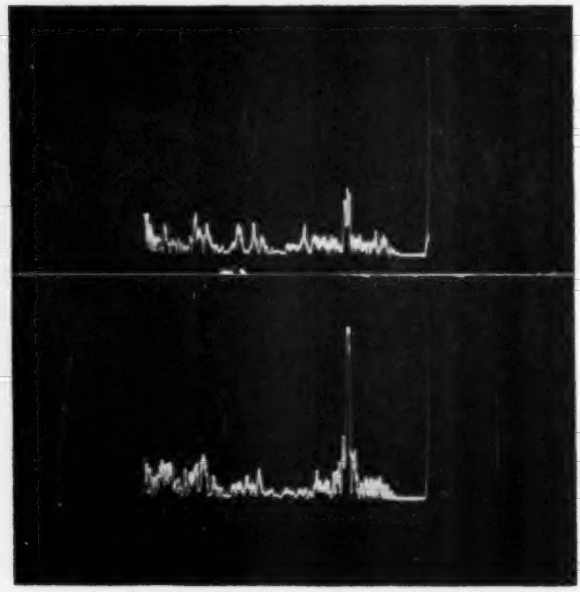

FIG. 4A. *Top*, tape tension 1.75 ounces, flutter 0.2% peak to peak at 2700 cps. *Bottom*, tape tension 3.5 ounces, flutter 0.8% peak to peak at 2700 cps.

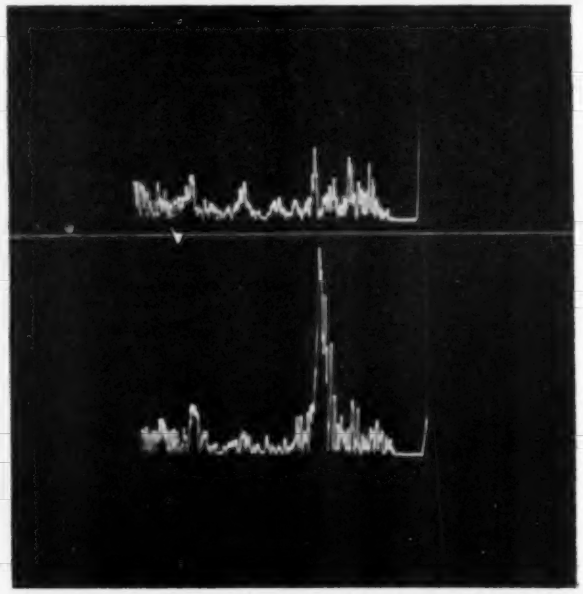

FIG. 4C. *Top*, head position 1.5 in. from capstan, flutter 0.3% peak to peak at 1800 cps. *Bottom*, head centered in 18-in. span, flutter 0.8% peak to peak at 1800 cps.

ings near the beginning and the end of a 10.5-in. reel of tape.

The effect of changing the length of the span is illustrated in Fig. 4B, in which the idler roller is moved from its normal position of 12 in. to a new position of 18.5 in. from the capstan drive. The frequency of the "spike" is seen to decrease from 2700 to 1800 cps, but the amplitude has increased appreciably. This amplitude increase may be due either to changes in the loss *vs* frequency properties of the tape, or to higher frictional excitation components generated at the lower frequency.

For a fixed length of span and tape tension, the amplitude of the FM component varies considerably with the position of both the excitation force and the active record (or reproduce) head. The center of the tape span corresponds to a natural current (velocity) maximum as shown in Fig. 2, and also to an "impedance" minimum, so that one would expect that a head placed at this position would experience the maximum amplitude of FM effect. Such was found to be the case, as illustrated in Fig. 4C, which shows the FM spectra for two head positions, one in the center of an 18-in. span and the other 1.5 in. from one end.

A number of different magnetic tape constructions were tested in an attempt to study the effect of the tape properties on flutter. Plastic tapes having backing thicknesses of 1.0, 3.0, and 5.0 mils were tested, and the resulting flutter frequencies were found to be unchanged from those of standard tape with 1.5-mil backing. This would seem to confirm the longitudinal vibration theory, according to which the vibrations are independent of tape thickness. Flutter spectra of paper tape (see Fig. 5) showed a greater profusion of high-amplitude components which are probably due to the increased surface roughness.

LISTENING TESTS

Since the basic exciting forces of high-frequency flutter are random friction variations, the resulting audible disturbances are apparent as noise riding behind high-frequency signals. The mechanical resonance of the tape further modifies this effect to sound like noise which has been passed through a narrow band-pass filter. The audio spectrum of a 5-kc tone showing distinct flutter side bands at 2 kc and at 8 kc is shown in Fig. 6. The discrete frequency character of the FM noise components gives rise to a beat note effect which is particularly noticeable when one is listening to a gliding tone played over a tape system. The effect is similar to the sound of rushing air which accompanies the high-pitched note of a peanut whistle.

A curious anomaly was noted during the study of the subjective effects of FM noise. In the recently issued IRE standard on flutter measurements,[2] a 3000-cps test tone is specified for the measurement of flutter, and a "flutter index" is suggested for the comparison of flutter components occurring at different rates. For rates from 5 to 200 cps the suggested flutter index, I, is given by

$$I = \frac{kf}{600r}$$

where k is the per cent rms flutter in this system, r is the flutter rate, and f is the frequency of the test tone. This implies that the sensitivity of the ear to flutter depends solely on the amplitude of the flutter side-band components. It also implies that the ear is relatively insensitive to high-frequency flutter components such as those associated with FM tape noise. However, in actual listening tests on FM tape noise, flutter components of only 0.2% peak-to-peak amplitude occurring at a rate of 3 kc can be discerned in a 5-kc tone.

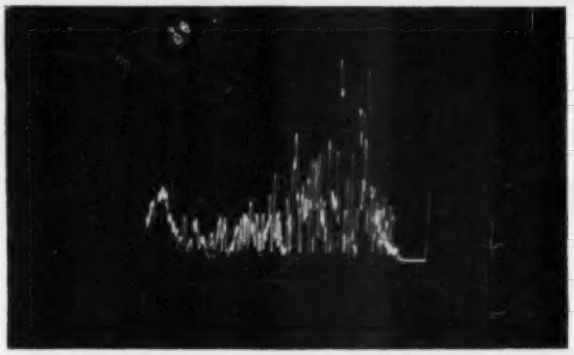

FIG. 5. Flutter spectrum of paper tape. Highest amplitude components are approximately 2% peak to peak.

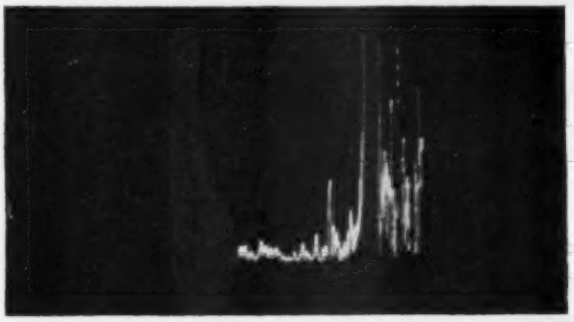

FIG. 6. Spectrum of a 5-kc reproduced tone showing a 2-kc FM side-band component 46 db down from the carrier.

In view of this apparent discrepancy, a series of listening tests were conducted with an electronically deviated oscillator source at 5- and 10-kc test frequencies. The flutter index was observed to be virtually constant as the flutter rate was varied from 100 cps to 3 kc. With the spectrum

[2] IRE Standards on Sound Recording and Reproducing: Methods for Determining Flutter Content, 1953.

analyzer, the side-band components were observed to decrease in amplitude with increasing flutter rate according to prediction, but the subjective effect of the flutter did not seem to follow this relationship. With a 3-kc test signal, however, the flutter index did appear to follow the relationship outlined in the IRE flutter specification. From these observations, it would seem that existing flutter index formulas may not be entirely valid when extended to cover these high-frequency flutter phenomena.

PRACTICAL CONSIDERATIONS

From the previously described experiments, several methods of minimizing or eliminating FM noise may be inferred. The most obvious is that of providing stabilizing rollers to contact the tape at or near the recording heads. The inertia of these rollers need not be very large to make them be effective against high-frequency vibrations. Small ball bearings about a half-inch in diameter placed so that the tape rides on the outer race have been found to be quite sufficient. It must be recognized, however, that rollers acting on the tape near the recording heads may introduce other problems such as faulty tape tracking or poor head contact, which may prove to be equally objectionable. The desired motion-stabilizing effect is obtained in some machines by positioning the heads so that they bear directly against the tape as it passes over the drive capstan.

It has been established that friction plays a large part in FM noise. Excessive tape tensions, sharp edges of the heads or guides contacting the tape, and build-up of foreign material on the head surfaces may all contribute to abnormal friction and hence aggravate FM noise. Another condition which may contribute to FM noise is head wear. Deep grooves worn in the recording head tend to pinch the edges of the tape and may greatly increase the friction.

Recognition of FM noise as distinct from AM noise is not always easy. However, any noise which seems to be associated primarily with high-frequency recorded signals, and exhibits a beat-note effect as the frequency is varied, can be suspected. A good way of corroborating this suspicion is the temporary application of a roller to the tape near the head while noting the effect on high-frequency signals. The effect is often a pronounced decrease in system noise, indicating the presence of FM components.

Defects in Magnetic Recording Tape: Their Cause and Cure*

FRANK RADOCY†
Audio Devices, Inc., Glenbrook, Connecticut

Photomicrographs by PHILLIP O. GRAVELLE

The presence of imperfections in the surface of magnetic tapes has been a problem in the computer, telemetering, and home recording fields. Tape squeal, sticking, and level variations have been caused by deposits on the head due to the shearing of imperfections in the oxide. Because of the effect of level variation in the computer field, the latter phenomenon has generally been referred to as "dropout."

Through improved binder formulation and coating techniques, a precision tape has been developed in which coating imperfections are virtually eliminated as a source of dropouts.

THE IMPERFECTIONS found on the surfaces of magnetic recording tapes have been responsible for a number of the common problems encountered during recording. As the general level of recording quality has risen, and as magnetic tape has found use in increasingly critical applications, such surface defects have assumed greater and, in some cases, overwhelming importance.

Growing interest in narrow-track recording for stereophonic, computer, and telemetering applications several years ago pointed to the need for the elimination of defects and led to the start of a project for the development of a defect-free tape. Work on this new tape, to which we have given the name "Extra Precision," has, in turn, led to profound improvement in our standard tape as well.

The overwhelming majority of imperfections project out from the magnetic surface. When these defects slide over various surfaces of a tape transport mechanism, one of several things occurs. If the projection is hard, the tape will be lifted away from the heads, causing a loss in signal, especially at the higher frequencies. If the projection is softer, it will be crushed, resulting either in a deposit on the heads or a smear on the magnetic coating. This, in turn, increases the tape-to-head friction, causing tape squeal, sticking, and erratic tape motion. Such poor performance is intolerable in both amateur and professional fields.

Through improved binder formulation and coating techniques, Audio Devices, Inc., has virtually eliminated the major defect—the "nodule" or clump of magnetic material shown in Fig. 1. At the start of this project several years ago, the presence of nodules was unquestionably a serious problem, leading to several hundred defects per reel of tape. Today, our standard tape has no nodules, and the remaining defects are so few and so small as to be of no significance in ordinary recording. By careful selection of raw materials and by observing exceptional cleanliness throughout the manufacturing process, the number of defects in Extra Precision tape and the size of these defects have been further reduced to the point where we consider both negligible even for computer and telemetering purposes.

TYPES OF DEFECTS

Two types of defects exist. Removable faults form one class, and permanent imperfections constitute the other group. As a subsequent statistical analysis will show, most defects are removable and are caused by factors within the recordist's control. It is hoped that this discussion will help the recordist minimize the occurrence of such faults by use of adequate preventive maintenance.

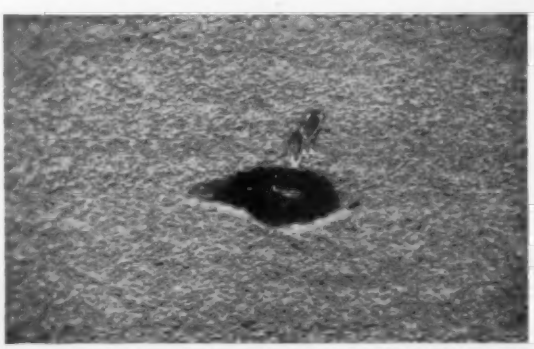

FIG. 1. Photomicrograph of "nodule," magnification 250 diameters.

* Presented at the Sixth Annual Convention of the Audio Engineering Society, New York, October 14-16, 1954.

† Director of Quality Control.

REMOVABLE DEFECTS

A photomicrograph of the type of defect which we call "cellulose acetate fibers"—a type of defect which we found to be very common, incidentally—is shown in Fig. 2. To

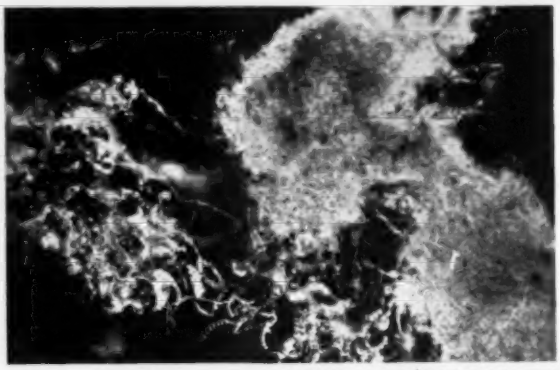

FIG. 2. Photomicrograph of "cellulose acetate fibers," magnification 250 diameters.

the unaided eye this appears as a speck of white powder. This photo clearly shows the fibrous character of the defect.

The width of the individual fibers is about 4 microns or 0.00015 in. Notice the resemblance of the individual fibers to metal shavings produced on turning lathes. The defect pictured here was formed in much the same manner: Bits of sharp grit lodged in the pressure pads scored the cellulose acetate backing, resulting in an accumulation of these fibers; sections of this accumulated mass would break loose occasionally and become sandwiched between the tape layers. On the second pass, fibers which had been transferred to the coated side of the tape accumulated on the various transport members and produced a loss in signal when the particular sections of tape to which they adhered passed over the heads.

The same kind of defect can be produced through the agency of any metallic surface which happens to be in contact with the backing. Stationary tape guides are great offenders in this respect. Distorted reel flanges also contribute considerably to the origin of this type of defect, since they scratch and score the backing.

Another form of the same defect appears more powder-like in appearance. This is due either to a more brittle backing material or to speed conditions that are not conducive to the formation of thread-like shavings.

The wise recordist will carefully examine his tape transport and eliminate the sources of this defect.

One of the most prevalent kinds of defect, called "oxide stripping," is shown in Fig. 3. This type of defect is comparatively large, running from 6 to 8 mils in width and 30 to 40 mils in length. To the unaided eye it appears to be a sliver or flake of the magnetic coating compound. The photomicrograph of Fig. 3 reveals the layer-like formation of this mass, indicating that the material is not just a flake of the coating compound, but rather an *accumulation* of coating compound.

To explain the origin of this trouble, we have drawn Fig. 4, showing one edge of the pole-piece facing the direction of tape travel. The tape is shown being forced against the side wall of the groove which has been worn in the pole-piece. This occurs when a tape is wider than the worn groove or when skewing occurs, resulting in a distortion of the tape edge and exposing the coating to extreme pressures. The coating compound is squeezed out to the top edge of the groove, forming the layer-like formation observed in Fig. 3.

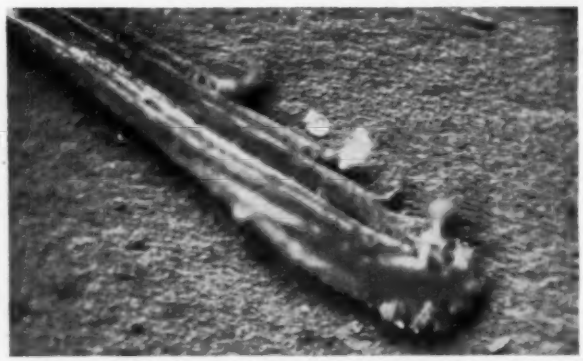

FIG. 3. Photomicrograph of "oxide strippings," magnification 250 diameters.

This mass will break away and become sandwiched between the wound tape layers on the take-up reel and will ultimately find its way onto the head assemblies, causing frictional problems, dropouts, and generally poor performance, or it

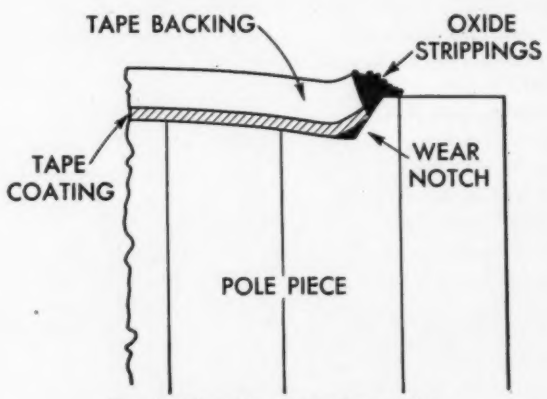

FIG. 4. Schematic of pole-piece section.

will become welded to the coated surface and remain as a permanent defect.

Unfortunately, the condition described in Fig. 4 is only too prevalent. Most head assemblies and tape guides in use are slightly grooved from wear. Tape skewing is always present, since no tape is perfectly straight throughout its entire length. Tape width may vary up to 3% of the total width and yet be within present national standards.

To minimize the aforementioned type of malfunction we recommend that the recordist clean the contact surfaces of his tape transport often, replace or stone heads when worn, and avoid abnormal tape tension to prevent the stretching which causes excessive skewing.

Figure 5 is a photomicrograph of the type of defect known

FIG. 5. Photomicrograph of "edge strippings," magnification 250 diameters.

as "edge stripping." To the unaided eye this difficulty appears as a speck of pale-reddish powder on the coated surface. At 250 diameters it is possible to discern tiny particles of cellulose acetate and coating compound. The particles average about 1 mil in diameter and are odd-shaped.

The origin of these particles is the same as that of the defect referred to above as "oxide stripping." Referring to Fig. 6, which is the same head pictured in Fig. 4, we note that, in this instance, the edge of the tape is butting against the wall of the worn groove so that both the backing and coating compound are being chipped; these particles, too, may ultimately find their way onto the tape coating or onto contact points of the transport mechanism by means of the mechanical transfer process previously described.

The pole-pieces of the head assembly are not the only points of origin for the "edge strippings" and "oxide strippings." Any surface which is in contact with the tape edge

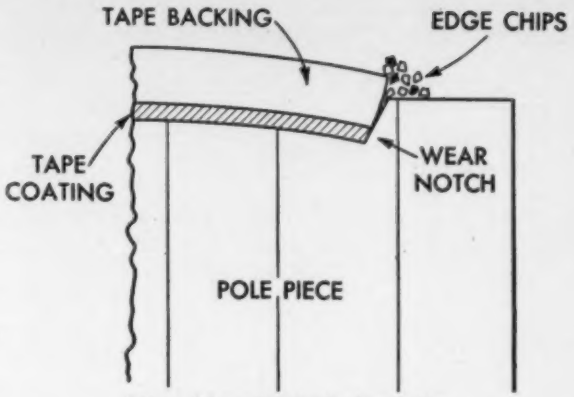

FIG. 6. Schematic of pole-piece section.

can produce similar results. Again, we recommend vigilant cleaning and replacement of worn tape-transport members.

In addition to the aforementioned sources of trouble, it should be noted that dust—picked up during storage in an unprotected manner—is a major removable defect. We recommend dust-free storage facilities for tape employed in computers, and suggest the use of dust-removing facilities on all tape-handling equipment employed in conjunction with computers.

PERMANENT DEFECTS

Figure 7 is a photomicrograph of a foil "deformation." It is volcano-like in structure and appears to the unaided eye as a nodule on the coated surface. The core of this defect was exposed when the coating compound was removed from the peak, revealing the bubble of air frozen into the plastic foil. This defect is primarily the concern of the plastic foil manufacturers, who, fortunately, are constantly improving the product they furnish to producers of magnetic tape.

Figure 8 is a defect of the variety called "coated fibers." This, too, looks like a nodule to the unaided eye, but after

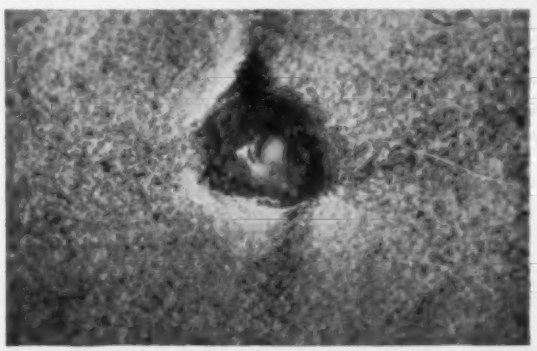

FIG. 7. Photomicrograph of "foil deformation," magnification 250 diameters.

FIG. 8. Photomicrograph of "coated fibers," magnification 250 diameters.

the top layer of coating compound has been worn away, the core of white cellulose fibers can be observed in the photomicrograph. This difficulty originates during the coating operation: Cellulose acetate fibers (which were wound between the foil layers before coating) pass through the foil cleaning operation and are overcoated. As a result of our study of tape defects, means have been found to avoid this type of defect.

DEFECT STATISTICS

Statistics have been gathered during the past six months, using a defect counter developed by Andreas Kramer and described by him in a separate paper.‡ The counter employed multiple 50-mil playback heads and operated at 60 ips. Tests were made with a pulse width of 7 μsec and pulse packing of 100 bits per inch. On playback, any signal weaker than 50% of saturation was considered a defect. Each tape was run twice in the same direction to determine which defects were repeatable.

The results of this study are shown in Table I. In the 600 reels tested, 88 repeatable defects were found. This is equivalent to 6.8 reels per defect or 0.14 defect per reel.

For those who have the necessary facilities for examining and removing defects, a breakdown of the repeatable defects is given: 56 of the 88 defects yielded by the study proved to be of the removable kind, leaving 32 permanent defects. This is equivalent to 18.7 reels per defect or about 0.05 defect per reel. Of the 88 repeatable defects found, only the 24 labeled "foil deformations" and "coated fibers" were produced by the coating process, or 40 reels per defect and 0.025 defect per reel. The remaining 64 defects are a result of subsequent handling of the tape.

‡ Mr. Kramer's paper will be published in a forthcoming issue of the JOURNAL.

TABLE I.

Defect study	
Number of reels tested	600
Reel size	1250 × ¼
Number of repeatable defects	88.00
Number of repeatable defects per reel	0.14
Number of reels per repeatable defect	6.8

Defect breakdown			
Removable defects		Permanent defects	
Cellulose acetate fibers	32	Foil deformations	8
Oxide strippings	12	Cellulose acetate flakes	16
Edge chips	8	Oxide strippings	4
Lint	4	Punctures	2
		Embedded grit	2
Total	56		32

Number of permanent defects per reel	0.05
Number of reels per permanent defect	18.70

Table II shows the number of repeatable defects found in Audio-brand Extra Precision tape compared with the number of defects found in two other tapes of the same class. According to our tests, Audio EP tape shows only one-sixth as many defects as the next ranking tape.

TABLE II. Comparative Results of Defect Studies.

	Audio EP	Tape A	Tape B
Repeatable defects per reel	.14	1.00	11.00
Reels per repeatable defect	6.80	1.00	0.09

CONCLUSION

The fact that most defects appear to be produced *after* the coating operation is of great importance to the tape user since, with the proper knowledge, he can prevent most defects from developing. As compared with findings in previous studies of this type, the data presented above show a remarkable improvement in tape quality, as regards defects. It is now possible to manufacture — by mass production methods—a type of tape in which defects are significantly rare. At the same time, the quality of *standard* tape has also shown major improvement.

Correlation of Transient Measurements on Loudspeakers with Listening Tests*

MURLAN S. CORRINGTON†

Radio Corporation of America, Camden, New Jersey

The transient distortion of a loudspeaker may be measured by intermittently applying sine-wave bursts, consisting of four or sixteen cycles each, to the speaker. Each burst starts with the wave going through zero degrees and ceases, after the desired number of cycles has been counted off, with the wave once again crossing the zero axis. Each burst is followed by an "off" period whose duration is equal to that of the burst; the burst is then repeated. A microphone situated in front of the loudspeaker is gated to measure the sound "hangover" during the "off" period. A curve is then drawn of this transient hangover as a function of frequency. The correlation of the curve thus obtained with listening tests is discussed.

INTRODUCTION

WHEN a pianist strikes a note on the piano, the hammer hits the string and the string suddenly starts to vibrate and produces sound. At the end of the note, the damper suddenly stops the string and the sound ends abruptly. If this note is reproduced by a loudspeaker, the loudspeaker must start suddenly, produce the required sound, and then immediately stop. If the loudspeaker continues to produce its own characteristic sound after the note is ended, this undesired output probably will not be harmonically related to the next note and disagreeable distortion will result.

Since many sounds start and stop abruptly, it is evident that an important test of a loudspeaker is to observe the manner in which it builds up a sound when a tone is applied, and the way it stops emitting sound when the driving force is removed.

TONE-BURST EQUIPMENT

One test seems to come closer to giving a true measure of this transient response to suddenly-applied tones than any other.[1,2] In this test, sine-wave bursts are applied intermittently to the loudspeaker. A computer circuit turns the burst on at the precise instant when the sine wave goes through zero, counts off a predetermined number of cycles (four or sixteen) and then turns the burst off just as the wave is going through zero. The wave is left turned off for a prescribed number of cycles (usually the same as the "on" period) and then turned on again, and the sequence repeated.

Each burst of tone is applied to the voice coil of the loudspeaker. The sound developed by the loudspeaker, during the time when driving force is turned off, is picked up by a microphone, rectified, and used to drive automatic curve-drawing equipment. From the data thus obtained a curve is then plotted of the transient "hangover" as a function of frequency; this latter curve is compared with the steady-state sound-pressure curve.

A block diagram of the transient recorder is shown by Fig. 1. An audio oscillator generates continuous sine waves of the desired frequency. An electronic computing circuit opens the gate at the instant when a particular sine wave is going through zero degrees, counts off a given number of cycles (four or sixteen), and then closes the gate for an interval whose duration is equal to that of the "on" period. The continuous stream of tone bursts is amplified and applied to the loudspeaker in an anechoic chamber.

The microphone situated in front of the loudspeaker picks up the transient sound output of the loudspeaker. The gate following the microphone amplifier is permitted to remain open during the interval when the driving force is turned off, allowing for the time the sound is delayed in going from the loudspeaker to the microphone. The output from the gate is the sound output delivered by the loudspeaker *after* removal of the driving force; this sound output is the tran-

* Presented at the Sixth Annual Convention of the Audio Engineering Society, New York, October 14-16, 1954.

† RCA Victor Television Division.

[1] Murlan S. Corrington, "Transient Testing of Loudspeakers," *Audio Eng.*, 34, No. 8, pp. 9–13 (August, 1950). This article contains an extensive bibliography.

[2] Franz Brunner, "Untersuchungen an Lautsprechern," *Oesterreichische Zeitschift für Telegraphen-, Telephon-, Funk- und Fernsehtechnik*, 8, Nos. ½, 1-7 (1954).

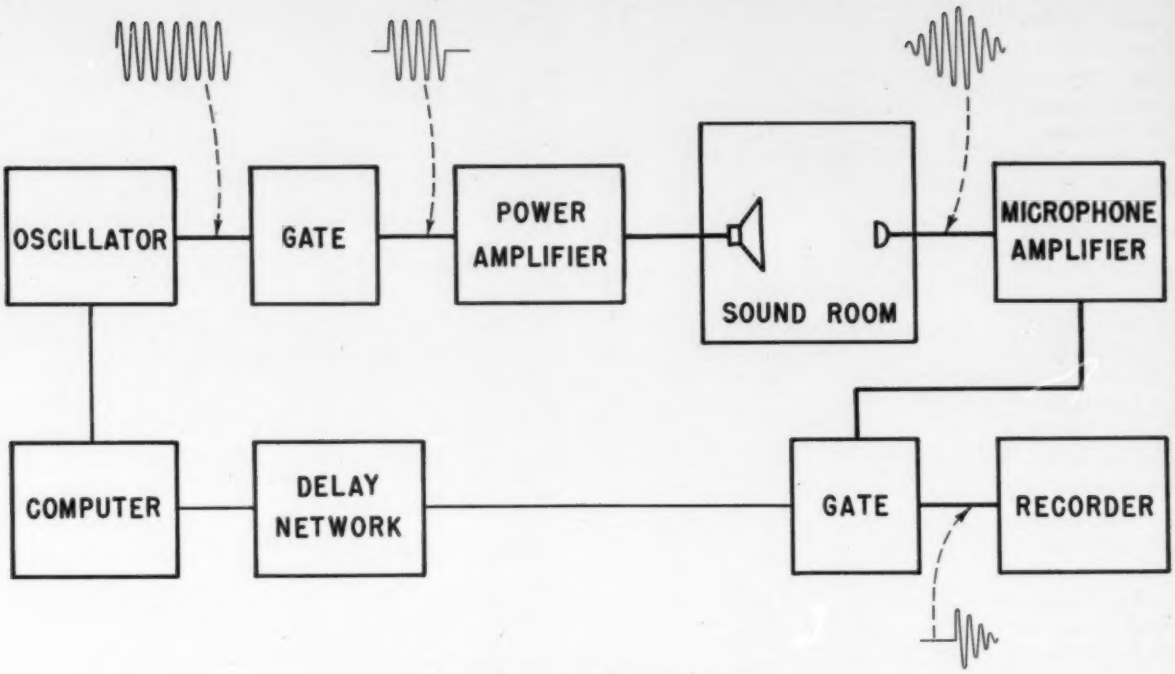

FIG. 1. Block diagram of transient recorder.

sient "hangover." This gated output is rectified, averaged, and applied to the recorder to produce a graph of the transient hangover at each frequency. The circuit details of this equipment are described in a paper by Kidd.[3]

COMPARISON WITH STEADY-STATE RESPONSE

To provide a steady-state response curve at the proper level for direct comparison with the graph of the transient response, gating is applied, *not* to the loudspeaker, but to the recorder so that the latter receives a signal 50% of the time. This gives a curve 6 db below the curve obtained if the recorder is not gated, and thus is comparable with the transient curve obtained when the recorder is turned off during the "on" period of the tone burst. Experience shows that the error introduced by the gating process is never more than one-half decibel at any frequency.

The transient response is usually drawn in two parts. Below 200 cps the tone burst consists of four complete cycles of the sine wave and above 200 cps, sixteen complete cycles are used. This 200-cycle changeover frequency is not critical, but was chosen so that it would fall in between the fundamental low-frequency resonance point and the region of cone "breakup."

[3] Marshall C. Kidd, "Tone-Burst Generator Checks A-F Transients," *Electronics*, **25**, 132-135 (July, 1952).

SOME EXPERIMENTAL RESULTS

The oscillograms of Fig. 2 show the transient response to a burst of tone for an 8-in. loudspeaker and a 12-in. loudspeaker, respectively, each at the low-frequency resonant point.

The upper curve is the current input to the voice coil. It is slightly distorted because of the limited low-frequency bandwidth of the amplifier. The next curve is the sound-pressure output as measured with a microphone. The bottom curve shows the transient distortion; it represents the sound output delivered by the loudspeaker after the driving force has been removed from the voice coil. This rectified output is applied to the curve-drawing equipment.

The curves of Fig. 3 are for the 8-in. loudspeaker at 900 and 3300 cps. Sixteen cycles of the tones are used in each burst. The 900-cps transient is caused by the rim resonance[4] and is down 15 db from the gated steady-state response. The 3300-cps transient hangover lasts longer and is caused by cone breakup. It is down 16 db from the sound-pressure curve.

The 8-in. loudspeaker has a small magnet and relatively low flux density in the air gap. The transient hangover is

[4] Murlan S. Corrington and Marshall C. Kidd, "Amplitude and Phase Measurements on Loudspeaker Cones," *Proc. I.R.E.*, **39**, No. 9, pp. 1021-1026 (September, 1951).

nearly as great as the main response. The 12-in. loudspeaker has a large ring magnet and some acoustical damping. The transient hangover at low frequencies is quite small. Compared with the steady-state response, it is about 18 db down.

The curves of Fig. 4 show the steady-state sound-pressure output, the transient distortion, and impedance curves for the 8-in. loudspeaker of Figs. 2 and 3. The fundamental resonance at 90 cps is easily seen in all three curves.

The rim resonance[4] occurs at 900 cps and is shown as point *A*. The rim is in violent oscillation and gives a sharp peak in the sound-pressure curve and a large transient. At 1000 cps, the rim is out of phase with respect to the rest of the cone and cancellation of the sound output occurs.

The cone has a series of resonances above 2000 cps. The curves show that even though the speaker has a fairly smooth sound-pressure curve above 2000 cps, there are many peaks in the transient response. For the resonances at 2300 cps and at 3300 cps, shown as points *B* and *C*, the sound-pressure peaks are only 1.5 db high, but there are very sharp peaks in the transient.

This loudspeaker has a boom in the bass and is somewhat disagreeable on speech and piano music. The extreme highs are missing. When this speaker is used for complex orchestral music, there are times when the high frequencies sound disagreeable momentarily. This apparently occurs when the transient peaks are excited.

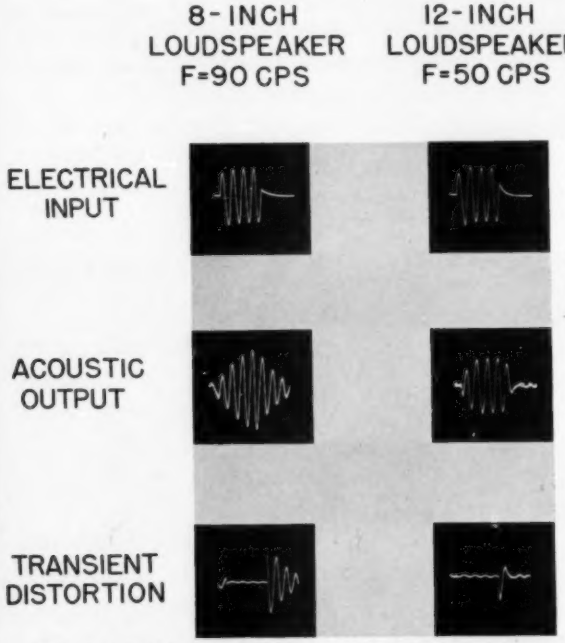

FIG. 2. Transient distortion for 8- and 12-in. loudspeakers.

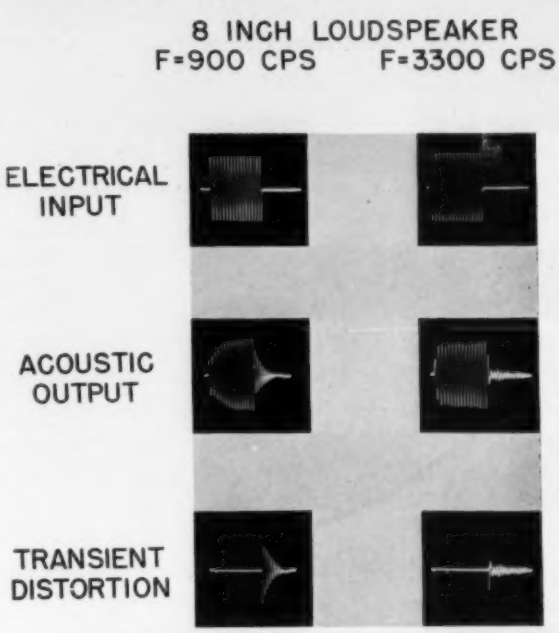

FIG. 3. Transient distortion for 8-in. loudspeaker.

The curves of Fig. 5 are for an 8-in. loudspeaker in a small open-back metal cabinet similar to that used with some communications receivers. The frequencies below 150 cps have been "rolled off" to avoid boom on male speech. These sound-pressure and transient curves are much more complex because of the combined effects of the metal cabinet and various diffractions. The four-cycle sequence tone burst has been continued to 420 cps for comparison. The

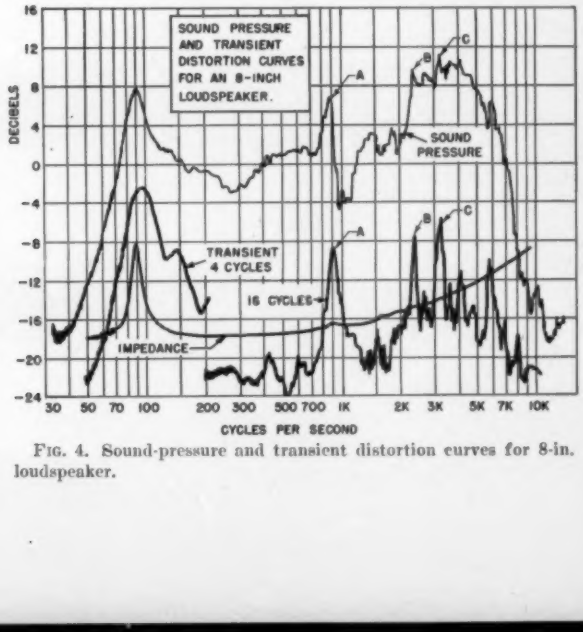

FIG. 4. Sound-pressure and transient distortion curves for 8-in. loudspeaker.

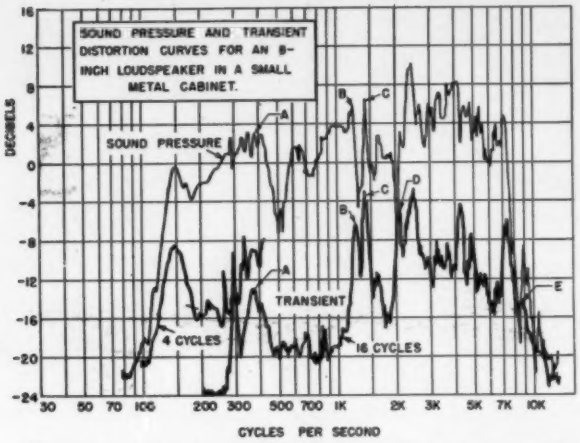

FIG. 5. Sound-pressure and transient distortion curves for 8-in. loudspeaker.

bad transient at 380 cps, shown as point *A*, is due to the open back. This peak would not be expected from the sound-pressure curve.

The bad transients at points *B* and *C* are in the region of maximum harmonic content of the singing voice and produce disagreeable distortion, especially if the singer has a strong vibrato.

At point *D*, the transient hangover is equal to the direct response; the loudspeaker puts out as much sound when it is turned off as it does when it is on. There are several bad transients at higher frequencies due to cone breakup. The one at point *E* is especially interesting. Here, too, the loudspeaker puts out more sound when it is turned off than when it is on.

This effect can be explained as follows: When the sine wave is suddenly applied to the system, it shock-excites the system and causes it to "ring" at its natural frequencies, which are near the applied frequency. If this transient "ringing" is of the right phase to cancel out the applied frequency for an appreciable time, the sound output will be reduced during the interval when the tone burst is being applied. When the driving force is removed, there is no longer any cancellation and the output, due to the transient ringing, is greater than when the tone burst is on.

It is fairly easy to find loudspeakers that put out more sound when they are turned off than when they are on. Imagine what this would do to a piano concerto, since the ringing frequencies are unlikely to be harmonially related to the applied frequency.

The loudspeaker of Fig. 5 is quite disagreeable on music; it has no "lows" and will not reproduce a singing voice properly. It is an inexpensive speaker suitable for intelligible reproduction of speech only.

The curves of Fig. 6 are for a 12-in. extended-range loudspeaker that is widely sold as part of a moderate-priced high-fidelity receiver. The gradual rise in the high end is compensated electrically to give a fairly flat response. There is more transient distortion in the low end than would be obtained if a bigger magnet and higher flux density in the gap were used. Cone breakup begins at 6000 cps. For an inexpensive loudspeaker this is a very good curve.

This speaker system has a wide range, a pleasing tone quality, and is widely accepted by the public. Some people, however, may object to the bass output of this loudspeaker as not being as "clear" as that of some units.

A small folded horn, such as that used in the more expensive dual units, or for small theater work, exhibits the response of Fig. 7. The crossover frequency is usually 800

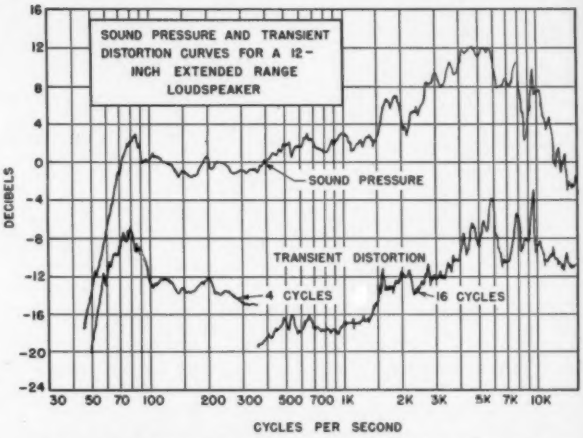

FIG. 6. Sound-pressure and transient distortion curves for extended-range loudspeaker.

or 1000 cps. This unit is characterized by unusually low transient distortion up to 5000 cps. The system is usually "rolled off" above this frequency. The diaphragm starts to "break up" above 5000 cps. The transient distortion is at least 20 db down from 800 to 5000 cps. This folded horn reproduces the speaking and singing voice very well and is very good on symphonic music. It will not distort, even at high output levels.

The smoothest curve we have been able to obtain in our laboratory is shown by Fig. 8. It is an 18 × 18 in.-square electrostatic unit similar to that developed by A. A. Janszen‡ at Harvard University. The moving element is 0.8

‡ Mr. Janszen now heads the Janszen Laboratory, 1 Gray Street, Cambridge 38, Massachusetts. A paper by Mr. Janszen, entitled, "An Electrostatic Loudspeaker Development," will appear in a subsequent issue of the JOURNAL.

mil of pliofilm with a graphite coating. Both curves are quite smooth and individual resonances are negligible. This speaker operates with 3000 volts bias and several hundred volts of signal. Below 700 cps, the stretched wires of the back electrode add some distortion. The transient distortion is down 18 db or more from 700 to 13,000 cps. This speaker, when used with a woofer, gives what we regard as unusually "clean" reproduction of voice and all musical instruments. We have often used it as a standard for listening tests.

The microphone used to obtain these curves was the RCA KB2C bantam velocity unit. Since this microphone gave transient curves with no repeating peaks for different speakers, it was felt that transient distortion introduced by the microphone was very low. It has been found that other microphones whose sound-pressure frequency response is flat within 1 db show transient response characteristics

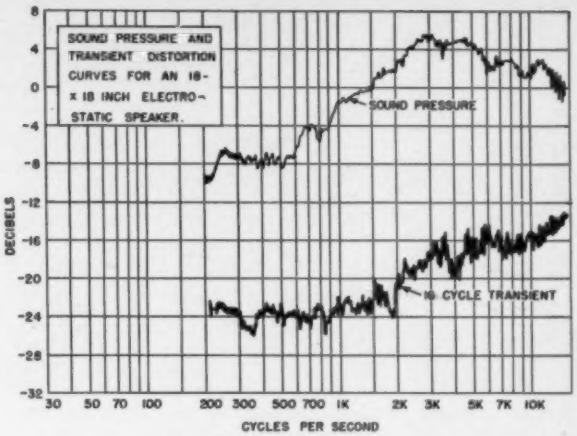

FIG. 8. Sound-pressure and distortion curves for electrostatic speaker.

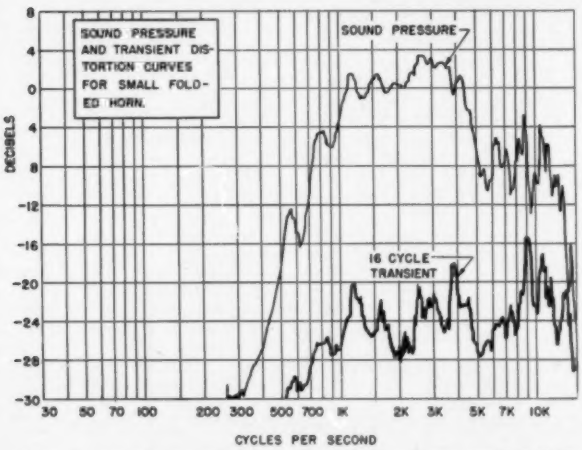

FIG. 7. Sound-pressure and distortion curves for small folded horn.

which are much worse. Abrupt discontinuities in microphone response, even though small, make some microphones unsuitable for the type of studies described in this paper.

CONCLUSIONS

Equipment has been developed to record the transient distortion of any audio amplifier, loudspeaker, or enclosure at all audio frequencies. A burst of tone consisting of four or sixteen successive cycles of a sine wave is applied to the system with the duration of the "off" period equal to that of the burst. The sound emitted when the driving force is turned off is recorded as a function of frequency. It is thus possible to give a numerical value for the transient distortion. Any speaker or sound system with less than 10 or 12% (18 to 20 db down) distortion over the useful range will be comparable to the best available.

This information supplements the steady-state sound-pressure measurements. We have never found any system with low transient distortion that did not also have a smooth sound-pressure curve; on the other hand, we have measured systems with fairly sharp and small peaks in the sound-pressure response that produced objectionable transient distortion.

There is very good correlation between transient distortion and subjective listening tests. Whenever there are peaks in the transient distortion, one can be sure that the listening tests will reveal unpleasant distortion, even though the sound-pressure curve is quite smooth. The transient test will not show small amounts of distortion in the amplifier; the latter should therefore be checked separately. It is a test of the loudspeaker only.

The effect of enclosure resonances and of diffraction effects is to produce transient ringing which coincides with the peaks in the sound-pressure curve.

Extensive measurements show that for a high-quality audio system the sound-pressure curve must be smooth and properly shaped, and that the transient distortion should be down at least 18 db throughout the range. One can then be fairly certain that the system will pass very careful listening tests.

ACKNOWLEDGMENT

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Multi-impedance, Multifrequency Crossover Networks for Multispeaker Systems*

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A unitized network system is described which makes possible a wide choice of crossover points and attenuation rates, matched to a wide range of speaker impedances for the purpose of achieving the most compatible performance from the speakers chosen for a multispeaker system.

A CROSSOVER network is a device that is an essential part of any reproducing system that is composed of a plurality of speakers where the individual loudspeakers are called on to operate over different parts of the audio spectrum. This method of operating with a reproducing system comprising more than one loudspeaker is in distinct contrast to a speaker system where there simply exists a plurality of speakers, all identical and all operating over the same frequency band. Thus, although an arrangement of, say, four wide-range speakers—all connected in parallel across an amplifier and all reproducing the entire program content—is without a doubt a reproducing system consisting of *several* speakers, it is not considered a *multi*speaker system. It may more properly be called a *distributed*-speaker system. On the other hand, a system comprising only two loudspeakers —where one reproduces the lower half of the audible spectrum while the other reproduces the upper half of the audible spectrum—is a multispeaker system (Fig. 1). In such a multispeaker system it is necessary to use a crossover network for optimum efficiency of the system. It should be noted that a multispeaker system may also be a distributed-speaker system, depending on whether the individual speakers are physically separated or not. If they are so physically separated, then it is a distributed multispeaker system. On the other hand, if the individual units are integrated into one unit, such as in a coaxial or triaxial speaker assembly, then it is simply a multispeaker system.

The importance of a crossover network in a multispeaker system lies in its ability to direct the proper frequencies to the speaker that will most efficiently reproduce those particular frequencies, and to detour another set of frequencies to the second (or third) speaker best capable of reproducing this latter set of frequencies.

Such division of the frequency spectrum into specialized-purpose loudspeakers, such as woofers and tweeters, designed specifically for operation within restricted bands, not only results in higher efficiency of reproduction of these individual bands but also serves to conserve audio power.

As a case in point, consider the situation in which a woofer and a tweeter are connected across an amplifier without benefit of a crossover network (Fig. 2). If the two

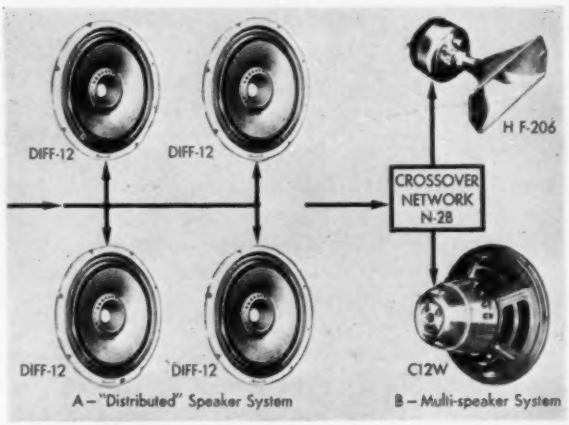

FIG. 1. Comparison—distributed speaker system versus multi-speaker system.

speakers are equal in impedance, then both speakers will draw an equal amount of power from the output line without discrimination as far as frequency is concerned.

An available 10 watts of audio power will be distributed in such a fashion that 5 watts of low plus high frequencies

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will be delivered to the woofer and 5 watts of low plus high frequencies will be delivered to the tweeter. Now, if we assume that the proportion of high to low frequencies in average program content is in the ratio of 1 to 4, we have a condition where the woofer receives 1 watt of high frequencies and 4 watts of low frequencies. So also does the tweeter. Using an arbitrary figure of 10% for the conversion efficiency of the speakers in the range *for which they were designed,* we find that the woofer will produce 0.4 acoustic watt of low frequencies, and the tweeter will produce 0.1 acoustic watt of high frequencies. In the ranges for which these speakers were not specifically designed, their conversion efficiency may be reduced tenfold. Thus, for high frequencies the woofer may have only 1% conversion efficiency, and the tweeter may exhibit similar low efficiency for low frequencies. The net result, acoustically, of putting a woofer and a tweeter directly across this output line where there are 10 available watts will be essentially only 0.4 *acoustic* watt from the woofer and 0.1 *acoustic* watt from the tweeter.

Now, when a dividing network is inserted into the system, the situation is altered considerably. The 8 available watts of low-frequency electrical energy are all earmarked for the woofer, which results in 0.8 acoustic watt of low-frequency power; and the 2 watts of high-frequency energy are all tagged for the tweeter, with a corresponding acoustic power output of 0.2 watt.

This example is somewhat an oversimplification of operating conditions. It does, however, serve to illustrate the conservation of power principle, which is one of the factors that should be taken into account when dealing with crossover networks.

One of the great advantages of multispeaker systems lies in the reduction of intermodulation effects between high and low frequencies by divorcing them physically from the same vibrating unit. Another advantage of multispeaker systems is the possibility of designing a reproducer which is intended to handle high frequencies only, to give optimum wide-angle dispersion of the high frequencies.

The manner in which a multispeaker system performs from the standpoint of speaker efficiency, intermodulation effects, spatial dispersion characteristics, and over-all "cleanliness" of response is thus determined, in great measure, by the crossover network which fixes what each speaker of the system shall receive.

There is no fixed rule which will determine the best network configuration for a multispeaker system, any more than there is any fixed rule by which one selects the speakers for such a system. Were there such a simple rule for high-fidelity systems, the high-fidelity idea might quickly lose its artistic impact. The things which make a system "hi-fi" are largely within the listener, within his own musical

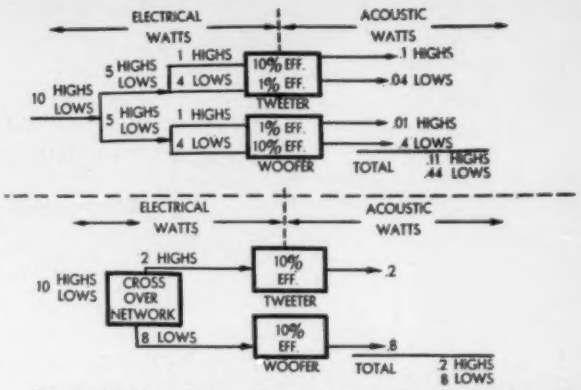

FIG. 2. Division of power into tweeter-woofer combination and resultant acoustic output. *Top,* without benefit of network; *bottom,* with network.

consciousness. And there are as many likes and dislikes, fable and fact, concerning high-fidelity systems and performance as there are preferences for certain types of musical compositions or criticisms of composers, conductors, and orchestras. We do not deplore this state of affairs. We welcome it, for it affords a wide latitude in system design in keeping with the individual taste of the constructor.

Consequently, we feel that a wide variety of reproducers and combinations of reproducers should be made available to the high-fidelity field. Such a variety of systems makes it necessary to provide a complementary system of networks compatible with the speaker system selected. Figure 3 illustrates the great many combinations of speaker systems that may be devised from a few basic component speakers. Each system differs in "character" of musical performance. One system is not necessarily better or worse than the other; it may just happen to suit one's musical taste better, or be more compatible with one's pocketbook. It should be recognized, however, that, even though one may start with a simple speaker of the "hi-fi" variety, this simple basic speaker may eventually become the pivot point around which a more elaborate system may be developed. Thus, a choice of networks for such an expandable system should likewise be compatible with both the new additions to the system as well as with the basic "building-block" speaker.

What determines the compatibility of a network with a loudspeaker system?

It is of prime importance in tying a multispeaker system to a network that the network impedance match the loudspeaker impedance. Although this is rather a straightforward objective, it is not accomplished in as straightforward a manner in practice, especially when new speakers are to be added to an already existing speaker of a different impedance. The second factor in the compatibility scale is the crossover frequency. The selection of the proper cross-

over point is dependent not only on the loudspeakers of the system but also on the musical preferences of the listener. The third factor involved in the compatibility question is the rate of attenuation of the network at the crossover frequency. The choice of this latter factor is a function both of the characteristic operation of the loudspeaker and the individual's personal preference. These three factors—impedance, crossover frequency, and attenuation rate—are

Although speaker impedances are fairly well standardized in 4-, 8-, and 16-ohm families, it is possible—on a purely listening basis—to select a woofer of, say, 4 ohms and a tweeter of 16 ohms as the two speakers which shall comprise a particular system. The constructor of such a system must next locate a network that will match these two different impedances. It is possible, too, that for a three-way system he has selected a 4-ohm woofer, a 16-ohm midrange speaker,

Woofer	Impedance	Mid-Range	Impedance	Tweeter	Impedance	Network or Filter
C8W	8 ohms			4401	6 to 16 ohms	N-1
C12W	8 ohms	C8W	8 ohms	4401	6 to 16 ohms	N-1
C8W C8W C8W C8W	8 ohms 8 ohms 8 ohms 8 ohms			4401	6 to 16 ohms	N-1
Dif-8 (woofer section)	8 ohms	Dif-8 (mid-range section)	8 ohms	4401	6 to 16 ohms	N-1
C12W	8 ohms	Dif-8 (mid-range section)	8 ohms	4402 Dif-8 (tweeter section)	4 to 8 ohms or 10 to 16 ohms 8 ohms	N-1
C8W Dif-8 (woofer section)	8 ohms 8 ohms	Dif-8 (mid-range section)	8 ohms	4401	6 to 16 ohms	N-1
6300	6 to 12 ohms			4401	6 to 16 ohms	N-2B
6300 6300	6 to 12 ohms 6 to 12 ohms			4402	4 to 8 ohms or 10 to 20 ohms	N-2B
C12W	8 ohms	6300	6 to 12 ohms	4401	6 to 16 ohms	N-1
C15W	4 to 8 ohms or 10 to 20 ohms	6300	6 to 12 ohms	HF-206	8 ohms	N-2A N-2B
Dif-12 (woofer section)	8 ohms	Dif-12 (mid-range section)	8 ohms	4401	6 to 16 ohms	N-1
C12W Dif-12 (woofer section)	8 ohms 8 ohms	Dif-12 (mid-range section)	8 ohms	4402	4 to 8 ohms or 10 to 20 ohms	N-1
C12W Dif-12 (woofer section)	8 ohms 8 ohms	Dif-12 (mid-range section)	8 ohms	HF-206	8 ohms	N-2B
C15W Dif-12 (woofer section)	4 to 8 ohms or 10 to 20 ohms 8 ohms	Dif-12 (mid-range section)	8 ohms	HF-206	8 ohms	N-2A N-2B
C8W 308 (woofer section)	8 ohms 8 ohms	308 (mid-range section)	8 ohms	308 (tweeter section)	8 ohms	—

Woofer	Impedance	Mid-Range	Impedance	Tweeter	Impedance	Network or Filter
C12W 308 (woofer section)	8 ohms 8 ohms	308 (mid-range section)	8 ohms	308 (tweeter section)	8 ohms	—
C12W 6301 (woofer section)	8 ohms 8 ohms			6301 (tweeter section)	8 ohms	—
C15W	4 to 8 ohms or 10 to 20 ohms	6301 (mid-range section)	8 ohms	6301 (tweeter section)	8 ohms	N-2A
C12W	8 ohms	6301 (mid-range section)	8 ohms	6301 (tweeter section)	8 ohms	N-2A
C12W 312 (woofer section)	8 ohms 8 ohms	312 (mid-range section)	8 ohms	312 (tweeter section)	8 ohms	—
C15W 312 (woofer section)	4 to 8 ohms or 10 to 20 ohms 8 ohms	312 (mid-range section)	8 ohms	312 (tweeter section)	8 ohms	N-2A
C15W 315 (woofer section)	4 to 8 ohms or 10 to 20 ohms 8 ohms	315 (mid-range section)	8 ohms	315 (tweeter section)	8 ohms	—
C12W	8 ohms			4408	6 to 16 ohms	N-2A
C12W	8 ohms	4408	6 to 16 ohms	4401	6 to 16 ohms	N-1 N-2A
C15W	4 to 8 ohms or 10 to 20 ohms			4409	6 to 16 ohms	N-2A
C15W	4 to 8 ohms or 10 to 20 ohms	4409	6 to 16 ohms	HF-206	8 ohms	N-2A N-2B
C15W	4 to 8 ohms or 10 to 20 ohms			Cobra-flex-2 with T-30	8 ohms	N-2A
C15W	4 to 8 ohms or 10 to 20 ohms	Cobraflex-2 with T-30	8 ohms	HF-206	8 ohms	N-2A N-2B
C15W	4 to 8 ohms or 10 to 20 ohms	Cobraflex-2 with T-30	8 ohms	HF-206	8 ohms	N-3

FIG. 3. Some suggested two-way and three-way systems using University loudspeakers and University crossover networks and high-pass filters.

the catalytic functions performed by a network to enable the fusion of the acoustic elements into a satisfactory compatible system.

It has been indicated that the choice of these various operating parameters is considerably dependent on the listener's taste rather than on cold black-and-white measurement. The wide variety of speakers available from different manufacturers indicates, to some degree, that personal preference plays a major part in the selection of a loudspeaker. The good name of the manufacturer, the cost of the item, the word-of-mouth reports, the musical education of the listener, his auditory acuity—all these, and more, are what make an individual buy a particular speaker, rather than the published specifications alone. Consequently, there are widely varying ways of operating speaker systems.

Let us examine these various factors involved in compatibility to find how they are tied to subjective listening tests.

and an 8-ohm tweeter. Then he must locate a network that will take care of these three impedances. Such problems of impedance-matching the speakers to the network are rather straightforward technically; the system builder can put his own network together. If, however, he wants to save himself this labor, he can avail himself of unitized network components like those shown in Fig. 4. With these two units, known as the N-2A and N-2B networks, it is possible to select almost any combination of 4-, 8-, or 16-ohm impedances; they can all be of the same value, or they can be scrambled in any desired manner without changing the crossover frequency selected.

An examination of the internal configuration of this network, as shown in Fig. 5, reveals how this is accomplished. If we had an 8-ohm woofer and an 8-ohm tweeter and the desired crossover were at 700 cps, the speakers would be connected to the network as shown in Fig. 5A. If it were a 16-ohm system designed for the same crossover point, then

the connections shown in Fig. 5B would hold. If, on the other hand, the plan called for an 8-ohm woofer and a 16-ohm tweeter, crossing over at 700 cps, then the connections as shown in Fig. 5C would apply. It is not necessary to go through all the impedance combinations possible within a single N-2A or N-2B network; suffice it to say that from the 4-, 8-, and 16-ohm connections available at the input side of each of these networks it is possible to obtain many more combinations and permutations than the art presently demands—enough, we believe, to fulfill any magical combination conjured up by the most discriminating "hi-fi" enthusiast.

As we have implied above, the choice of impedances required for a given system is specifically fixed by the speaker unit impedances. The choice of the crossover frequency, however, is partly dependent on listener preferences and partly dependent on speaker characteristics. Only the latter factor lends itself to more or less quantitative treatment.

Assume that the constructor has selected a woofer on the basis of a type of low-frequency response that pleases him personally. Second, let us assume that this woofer has fairly good response out to 1 kc when used as a direct radiator in a bass-reflex type of enclosure and then tapers off rather rapidly, as shown in Fig. 6A. The upper limit of crossover

FIG. 4. University L/C frequency-dividing networks, models N-2A and N-2B.

frequency is dictated by the woofer characteristic. To effect the crossover at a frequency higher than 1 kc would result in a system with a hole in the crossover area. The region of permissible crossover frequencies lies below 1 kc for this loudspeaker. Let us now assume that this loudspeaker is to be used in a folded-horn enclosure. Such an enclosure may limit the upper frequency response of the speaker to perhaps 500 cps (Fig. 6B), and consequently the area of permissible crossover frequencies lies below 500 cps.

These are the limitations placed on the choice of crossover frequencies by virtue of the physical characteristics of the woofer and its enclosure. Similar restrictions are placed on

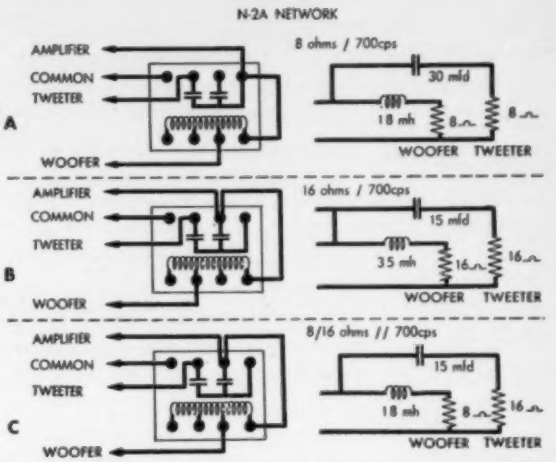

FIG. 5. Typical method of cross-connecting the N-2A network for different impedances.

the crossover frequency by the physical nature of the tweeter system selected. The more popular type of tweeter is the compression driver horn-loaded system (Fig. 1B)—first, because of its high conversion efficiency; second, because of its adaptability to horn designs favoring wide-angle dispersion of the higher frequencies. Horns are essentially high-pass filters. They have very specific low-frequency cutoff characteristics which are governed by their design parameters. Thus, as shown in Fig. 7A, a tweeter-horn system with a theoretical cutoff of 2 kc would be suitable for a system that would cross over at 3.5 kc or above. On the other hand, a horn with a theoretical cutoff at 600 cps (Fig. 7B) would be suitable for a system having its crossover at 750 cps or above. These, then, are the woofer and tweeter characteristics which determine the mechanical boundaries of the crossover frequencies.

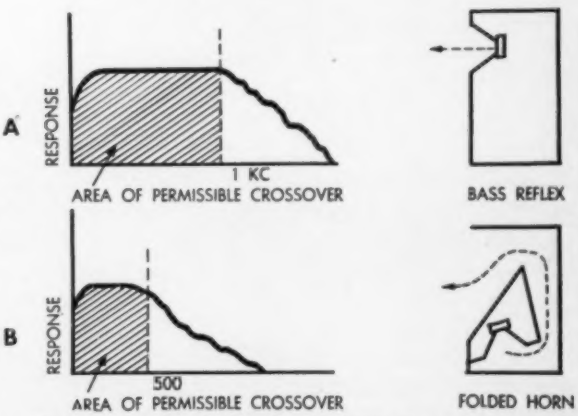

FIG. 6. The choice of crossover frequency for a woofer depends in part on the speaker itself and in part on the enclosure.

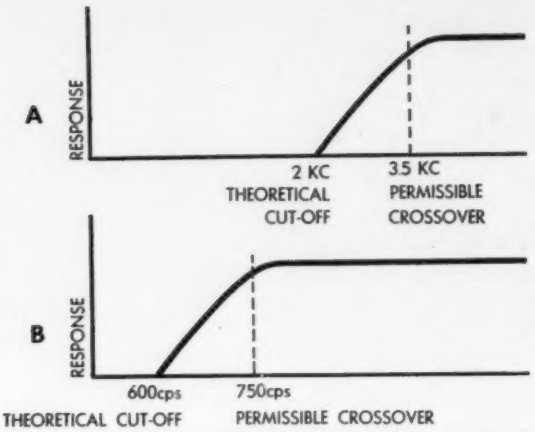

FIG. 7. Since horns are high-pass filters, their crossover frequencies should be chosen considerably above their theoretical cutoff point.

What makes an individual choose a loudspeaker with a particular low-frequency cutoff, as in the case of a horn-type tweeter? Here it is a matter of personal preference, musical likes and dislikes, and the complexity of the system that is being built. There is no magic number for a crossover frequency.

In a two-way system shall we cross over at 750 cps or at 2500 cps? *I* may cross over at 2500 cps, *you* at 750 cps, and neither of us will be right or wrong. It may simply be a question of, Do you like the middle frequencies to have a quality of "brilliance," as pertaining to a musical horn instrument, or do you prefer the middle frequencies to have the "mellowness" of a string instrument? If we want the "presence" of the horn-type instrument in the middle frequencies, we may cross over at 750 cps, allowing the horn tweeter to operate in that range and above. If we want the "mellowness" of the strings in the middle frequencies, we may cross over at 3.5 kc, allowing the vibrating cone to simulate, in this region, the body vibrations of the string instruments. These notions are more or less conjectural, so far as the pairing off of musical horn instruments with horn-type reproducers and the body-vibration type of instrument with cone-type loudspeakers is concerned. It is hoped that these ideas will offer at least a quasi-logical basis which may be used in selecting a speaker system.

It is important that the speakers chosen for a system be compatible as far as crossover regions are concerned. The individual speakers must have characteristics which overlap considerably at the crossover point; otherwise there will be "holes" in the acoustic output of the system, as shown in Fig. 8B. Once the speakers for the system have been selected on the basis that the rolloff characteristic of the one is compatible with the cutoff characteristic of the other, then the crossover frequency is rather rigidly fixed. This, however, is the exception and not the rule.

More often than not, the characteristics of the woofer, midrange, and tweeter units overlap considerably in each other's domains. This is actually an advantage in system design, as it allows a rather flexible crossover point. In order to make available a simple means of selecting that crossover frequency which best appears to suit the listener's personal standards and specific equipment, as used in his own home, the N-2A and N-2B multi-impedance networks (Fig. 9) have been designed to provide a variety of crossover points for various commercially available speaker impedances.

Thus, with the N-2A network, it is possible to cross over at 350 or 750 cps at impedances of 8, 16, or 4 ohms. With the N-2B network it is possible to cross over at 1250, 2500, and 5000 cps at impedances of 8, 16, or 4 ohms. The two instances given in Fig. 10 typify the manner in which such combinations are effected. Figure 10 shows the N-2B net-

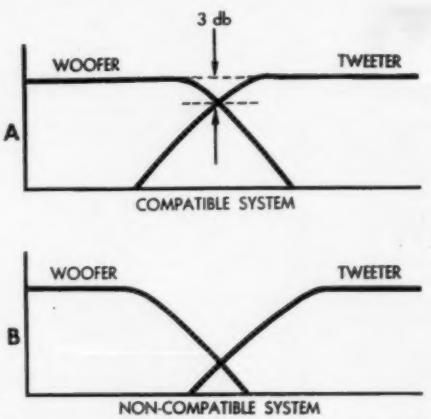

FIG. 8. Woofer and tweeter should have compatible rolloff and cutoff characteristics, respectively, to produce a smooth over-all characteristic.

work arranged for 8 ohms and for 2500-cps crossover. The terminal connections for crossover at 5000 cps are also shown in Fig. 10.

This multiplicity of impedance connections and crossover forms is intended not only to permit selection of the operating points best suited to a particular system but also to facilitate system expansion without rendering existing equipment obsolete. Thus, referring to the previous case of the woofer mounted in alternate types of enclosures (Figs. 6A, B) let us assume that one has started out conservatively with the 15-in. woofer in a bass-reflex enclosure and a tweeter plus an N-2A type of network connected for crossover at 750 cps. After a couple of years of indoctrination into the

"hi-fi" family and the accumulation of a few more dollars in the bank, the enthusiast decides to expand to a three-way system using the same woofer and the same tweeter; but *this* time the woofer is to be put into a folded-horn enclosure. The system builder will now find it necessary to drop his crossover point to a frequency well within the pass band of the horn-woofer combination—say to 350 cps—and then to add a midrange speaker to bridge from 350 cps to some frequency in the treble region. It is a simple matter to reconvert his N-2A network for 350-cps crossover instead of the 750-cps crossover originally employed. This is done by bridging the appropriate terminals. To cross over from the midrange unit to the tweeter units, he can use an N-2B network. As shown in Fig. 11, this will give him a rather wide choice of crossover points to experiment with, namely 1250, 2500, and 5000 cps, all of which are in the passband of the tweeter-horn system, thus making the system compatible.

A typical cross-connection of an N-2A and an N-2B network in an 8-ohm three-way system to effect crossover at 350 and 5000 cps is shown in Fig. 12. With these two networks it is possible to arrive at a wide variety of three-way systems with combinations of impedances and crossover points to meet practically any mode of operation, as indicated in Fig. 13.

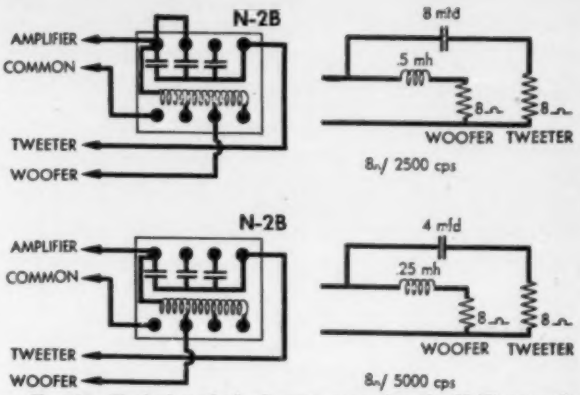

FIG. 10. Typical method of cross-connecting the N-2B network for different crossover frequencies.

One of the questions that often confronts the system constructor is that of attenuation rate at the crossover region, that is, how fast the output shall drop in one band and rise in the adjacent band. What confuses this picture is ambiguity concerning the precise part of the system in which this attenuation shall occur. Is it in the network that we want 6-, or 12-, or 18-db attenuation at the crossover point, or is it in actual acoustic performance of the speakers that we desire this attenuation characteristic? There is no clear-cut answer to this problem, because the network characteristics cannot be divorced from the characteristics of the speaker. What the network delivers to the speaker will be modified by the speaker performance itself. Figure 14 illus-

Connections for Use of Model N-2A as a 6db/oct Frequency Dividing Network for Two-Way Loudspeaker Systems

Voice Coil Impedance	Crossover Frequency	CONNECT Tweeter to	Woofer to	Amplifier to	and STRAP
8 ohms	350c/s	1 - 2	1 - 6	1 - 8	2 to 3 4 to 8
8 ohms	700c/s	1 - 2	1 - 7	1 - 8	4 to 8
16 ohms	350c/s	1 - 2	1 - 5	1 - 8	4 to 8
16 ohms	700c/s	1 - 2	1 - 6	1 - 8	3 to 8
4 ohms	700c/s	1 - 2	1 - 5	1 - 4	2 to 3 4 to 6

Connections for Use of Model N-2B as a 6db/oct Frequency Dividing Network for Two-Way Loudspeaker Systems

Voice Coil Impedance	Crossover Frequency	CONNECT Tweeter to	Woofer to	Amplifier to	and STRAP
8 ohms	1250c/s	4 - 5	5 - 8	1 - 5	1 to 2 to 3
8 ohms	2500c/s	4 - 5	5 - 7	1 - 5	1 to 2
8 ohms	5000c/s	4 - 5	5 - 6	1 - 5	——
16 ohms	2500c/s	4 - 5	5 - 8	1 - 5	——
16 ohms	5000c/s	2 - 5	5 - 7	1 - 5	——
4 ohms	2500c/s	4 - 5	5 - 6	1 - 5	1 to 2 to 3

FIG. 9. Available impedances and crossover frequencies of N-2A and N-2B as 6-db-per-octave frequency-dividing networks.

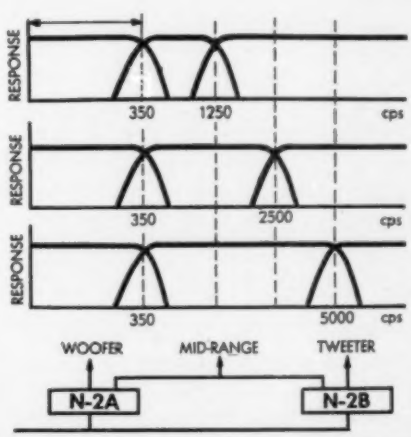

FIG. 11. The flexibility of the crossover selections available on the N-2A and N-2B networks provides a means of experimenting to determine the optimum crossover point for a given system.

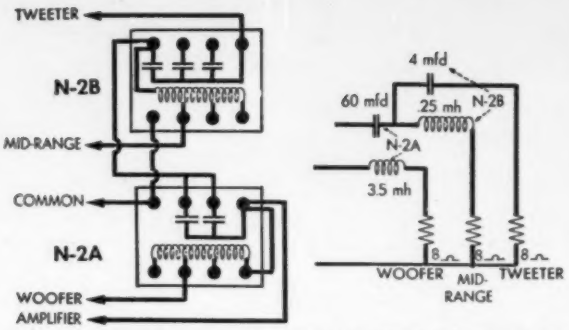

FIG. 12. A three-way system, with 6-db-per-octave rolloff, for 8 ohms, at 350 and 5000 cps, made with one N-2A and one N-2B network.

trates this condition. The left-hand column of graphs indicates a 12-db-per-octave attenuation crossover network operating with a speaker system in which each speaker in itself is relatively unrestricted as to frequency range. This might be the case where an individual has two 12-in. wide-range speakers and desires, for purposes of reducing intermodulation effects, to utilize one as a woofer and the other for the middle and upper range. When these wide-range speakers are operated on by the network with a 12-db attenuation rate at the crossover point, the resultant mode of operation will essentially follow the network characteristic.

Suppose, on the other hand, that one wishes to add a horn-type tweeter to a system which originally consisted of only a single wide-range speaker: if a 6-db per-octave network is used, as shown in the right-hand column of Fig. 14, the network will operate on the existing wide-range speaker in such a manner as to roll off its output at the rate of 6 db per octave above the crossover point. When the network operates on the horn-type tweeter unit, there will similarly be a 6-db drop in the *input* to the tweeter, but the output from the tweeter itself will be much more sharply reduced because of the natural low-end cutoff characteristic of the horn itself. The net result is that the use of a 6-db-per-octave network with the tweeter will cause much sharper low-frequency attenuation of the tweeter's output than will be the case for the wide-range speaker operated on by a 12-db-per-octave network.

Thus, the choice of attenuation rate expected from a network will depend in part on what the operating characteristic of the loudspeaker looks like, and, second, on how sharp a frequency separation the listener actually desires between the speakers of the system.

On this latter point, there are reasonable differences of opinion stemming from a desire to strike a balance between optimum frequency separation and minimum phase and transient distortion. A gradual rate of attenuation in a network will give less marked frequency separation but with good transient response. A steep attenuation characteristic will yield sharper frequency separation but at the expense of increased transient distortion.

Once the question of what attenuation rate to use has been answered, the desired result may be obtained with either the N-2A or N-2B network, or a combination of the two. Consider the case where it is desired to add a tweeter (8 ohms) to an already existing woofer through a high-pass filter with 12-db attenuation to cross over at 5000 cps. This may be done with a single N-2B network connected as in the upper part of Fig. 15. Again, this same

Voice Coil Impedance	Crossover Frequencies	CONNECT Tweeter to	Woofer to	Mid-Range to	Amplifier to	and STRAP
8 ohms	350 & 1250c/s	4B - 5B	1A - 6A	5B - 8B	1A - 4A	1A to 5B 2A to 3A to 1B to 2B to 3B 4A to 8A
8 ohms	350 & 2500c/s	4B - 5B	1A - 6A	5B - 7B	1A - 4A	1A to 5B 2A to 3A to 1B to 2B 4A to 8A
8 ohms	350 & 5000c/s	4B - 5B	1A - 6A	5B 6B	1A - 4A	1A to 5B 2A to 3A to 1B 4A to 8A
8 ohms	700 & 2500c/s	4B - 5B	1A - 7A	5B - 7B	1A - 4A	1A to 5B 3A to 1B to 2B 4A to 8A
8 ohms	700 & 5000c/s	4B - 5B	1A - 7A	5B - 6B	1A - 4A	1A to 5B 3A to 1B 4A to 8A
16 ohms	350 & 2500c/s	4B - 5B	1A - 5A	5B - 8B	1A - 4A	1A to 5B 3A to 1B 4A to 8A
16 ohms	350 & 5000c/s	2B - 5B	1A - 5A	5B - 7B	1A - 4A	1A to 5B 3A to 1B 4A to 8A
16 ohms	700 & 2500c/s	4B - 5B	1A - 6A	5B - 8B	1A - 3A	1A to 5B 2A to 1B 3A to 8A
16 ohms	700 & 5000c/s	2B - 5B	1A - 6A	5B - 7B	1A - 3A	1A to 5B 2A to 1B 3A to 8A
4 ohms	700 & 2500c/s	4B - 5B	1A - 5A	5B - 6B	1A - 4A	1A to 5B 2A to 3A to 1B to 2B to 3B 4A to 6A

*Units are designated as A and B.

FIG. 13. Connections for use of models N-2A and N-2B as a 6-db-per-octave frequency-dividing network for three-way loudspeaker systems.

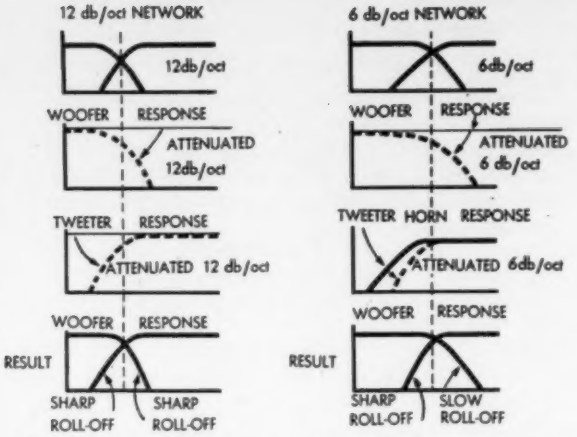

FIG. 14. Final acoustic output of speaker system depends on both speaker characteristic and network characteristic.

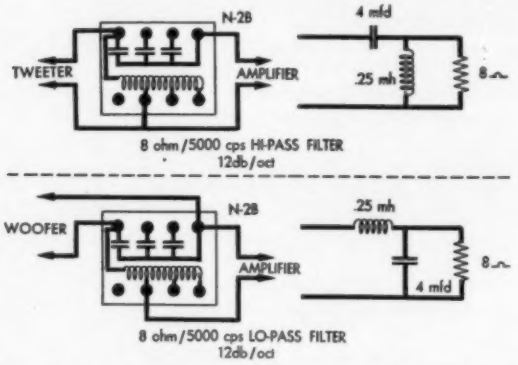

FIG. 15. Typical cross-connections for the N-2B network as a high- or low-pass filter.

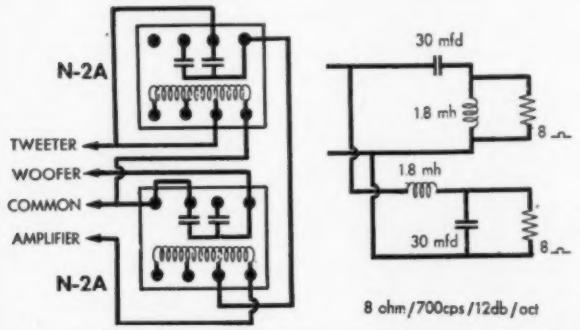

FIG. 16. Typical cross-connection of two N-2A networks to provide a two-way network with 12-db-per-octave attenuation.

box may be made to "double in brass" as a 12-db low-pass filter (as in the lower part of Fig. 15) by simply transposing the terminal connections. The N-2A and the N-2B net-

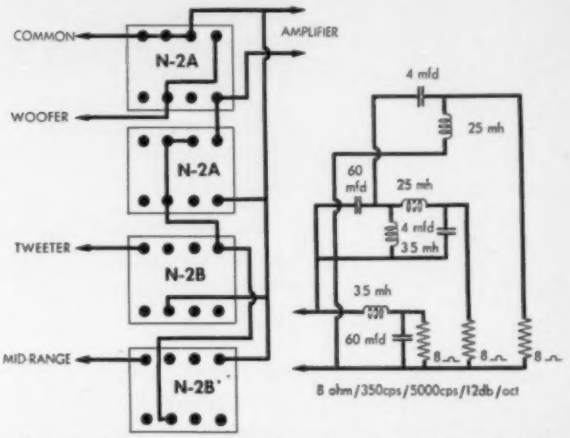

FIG. 17. Typical cross-connections for a three-way system with 12-db-per-octave attenuation, using two N-2A and two N-2B networks.

works may also be used in this fashion to accomplish 12 db of attenuation as both high-pass and low-pass filters at 4, 8, and 16 ohms, and at crossovers of 350, 700, 1400, 2500, and 5000 cps.

The N-2A and N-2B networks can also be arranged for use with two-way and three-way systems, with 12-db at-

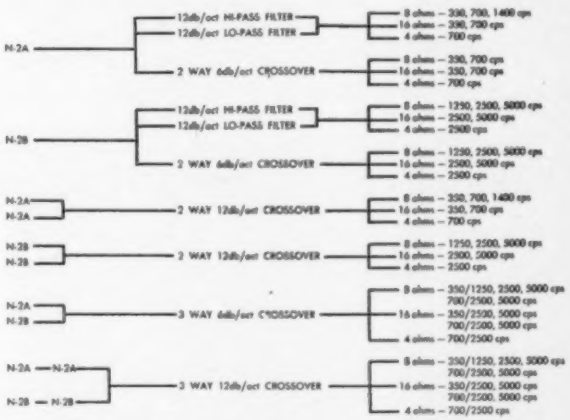

FIG. 18. Combinations of impedances, crossovers, and attenuation rates possible with the basic N-2A and N-2B networks.

tenuation at the crossover frequency. A two-way system with 12-db attenuation will require either two N-2A units or two N-2B units, depending on the crossover frequency selected. The manner in which this is accomplished is

shown in Fig. 16 for 8-ohm units and crossover at 700 cps. The approach is the same for all the other impedances and crossover points.

To bring the subject to its logical conclusion, that of a three-way system at 12-db-per-octave attenuation, we have the layout of Fig. 17. Although this last configuration is shown for 8-ohm units at crossover frequencies of 350 and 5000 cps, it is possible, of course, to cross-connect for a multiplicity of other impedances and crossovers.

With two basic units, the N-2A and N-2B networks, it has thus been possible to develop a family of applications (Fig. 18) covering practically all network configurations, at all commonly encountered impedances, and over a span of frequencies which should make it fairly easy to fuse almost any combination of speakers available in the "hi-fi" field into a compatible system.

The inaugural issue of the JOURNAL OF THE AUDIO ENGINEERING SOCIETY is expected to become a collector's item.

Copies of this first issue are still available: Price to members, $2.00 each. Price to non-members, $4.00 each.

All other back issues (April, July, and October, 1953; January, April, July, and October, 1954) are $1.00 each to members and $2.00 each to non-members.

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AES News

Audio Engineering Society Sixth Annual Convention—1954

The Sixth Annual Convention of the Audio Engineering Society was held in conjunction with the Audio Fair, at the Hotel New Yorker, New York City, October 14–16, 1954. At its annual banquet, Wednesday evening, October 13, the Society bestowed the following awards: the John H. Potts Memorial Award, the Emile Berliner Award, the AES Award, two citations, an honorary membership, and sixteen fellowships.

Potts Memorial Award to Joseph P. Maxfield

The John H. Potts Memorial Award, "for outstanding achievement in the field of audio engineering," was this year presented to Joseph P. Maxfield in recognition of his contribution in the field of audio engineering, including the development of electrical recording and reproducing systems for phonograph transcription and sound picture applications. His pioneering work led to important improvements in the field of studio, theater, industrial, and military acoustics.

Past recipients of the John H. Potts Memorial Award have been Harry F. Olson (1949), Howard A. Chinn (1950), Hermon H. Scott (1951), Frank L. Capps (posthumously, 1952), and Edward W. Kellogg (1953).

JOSEPH P. MAXFIELD

JOSEPH P. MAXFIELD received a B.S. degree from the Massachusetts Institute of Technology in 1910 and remained there for four years as an instructor and for graduate work. He then joined the engineering department of the Western Electric Company and engained in research work on the physical and electrical properties of microphone contacts. During World War I he aided in the development of methods for the acoustic detection of aircraft and sound ranging of artillery. From 1919 to 1926 he made many contributions to the Western Electric activities in the transmitting, recording, and reproducing of high-quality sound, out of which came public address systems, the design of broadcasting studios, the development of microphone technique, the orthophonic phonograph, and the adaptation of sound recording and reproducing apparatus to motion pictures.

From 1926 to 1929 Mr. Maxfield, on a leave of absence from Western Electric, was with the Victor Talking Machine Company, where he directed engineering and research on the orthophonic phonograph. He then returned to the Bell System, joining Electrical Research Products, Inc. From 1936 to 1942, as director of commercial engineering, Mr. Maxfield was responsible for the development of equipment for the measurement, analysis, and recording of sound and vibration. In 1942, he returned to the Laboratories as a physicist, but was granted a leave to become director of the NDRC Division of Physical Research at Duke University. From his return in 1944 until his retirement in 1947, Mr. Maxfield was with the acoustic products development group of the apparatus development department.

Berliner Award to Frederick V. Hunt

The second annual Emile Berliner Award, "for an outstanding development in the field of audio engineering," was presented to Frederick V. Hunt in recognition of his work in the field of acoustics, particularly in the recording and reproduction of sound. Especially significant are his analyses of tracing distortion in disk reproduction, his work on underwater sound systems, and his studies in acoustical measurement techniques.

FREDERICK V. HUNT

Recipient of the Emile Berliner Award last year (1953) was Henry C. Harrison.

FREDERICK V. HUNT was born in 1905 in Barnesville, Ohio. He received his B.A. and B.E.E. degrees from Ohio State University (1924–1925) and his M.A. (1928) and Ph.D. (1934) degrees from Harvard University. In 1945 he received Harvard's honorary Doctor of Science degree. From 1927 to 1946, Professor Hunt worked his way up the academic ladder at Harvard from assistant in physics to Gordon McKay Professor of Applied Physics. In 1954 he received an additional appointment as Rumford Professor of Physics.

For his work as founder and Director of the Harvard Underwater Sound Laboratory, 1941–1946, Professor Hunt received the Presidential Medal of Merit, and he continues to serve on various governmental advisory committees.

Professor Hunt is an Honorary Member of the AES, a Fellow and past president of the Acoustical Society of America, and a Fellow of the IRE. He is a member of the American Academy of Arts and Sciences as well as a member of the American Association for the Advancement of Science. He has written numerous research papers in acoustics and applied electronics and is author of the book *Electroacoustics*, published by Harvard University Press and John Wiley, 1954.

John D. Colvin Receives AES Award

The Audio Engineering Society Award to the person whose work has helped most the advancement of the Society was presented to John D. Colvin in recognition of his work for the Society during its formative years, particularly for his work on the steering committee before the Society came into being, and for his work as an officer, governor, and committee chairman after the Society was formed.

Past recipients of the AES Award are: C. J. LeBel (1949), Chester A. Rackey (1950), F. Sumner Hall (1951), Ralph A. Schlegel (1952), and C. G. McProud (1953).

John Colvin (right) receives AES Award from Sumner Hall, Chairman, Awards Committee, AES.

JOHN D. COLVIN was graduated from Bliss Electrical School, Washington, D. C., received his B.S. in electrical engineering at the Pennsylvania State College, and did graduate work in factory management at Columbia University. He spent two years with AT&T Long Lines in New York in the telegraph and teletypewriter department. For the next ten years he was employed by RCA in their Harrison and Indianapolis plants. For two years in Harrison and two years in Indianapolis he was responsible for the design of power tube manufacturing and testing equipment. During the remaining six years with RCA at the Indianapolis plant he was in charge of the development and design of their broadcast audio line. After leaving RCA, for five years Mr. Colvin discharged the duties of chief audio engineer with the American Broadcasting Company in New York and was responsible for the design of all company-owned studios, from the audio and acoustical side for the network. The next four years were spent as chief engineer and plant manager of Commercial Radio Sound Corporation in New York. Culminating these twenty years of experience in the broadcast and communications field, in 1953, he joined the Gates Radio Company in Quincy, Illinois, as director of engineering. Mr. Colvin was president of the AES, 1950-1951.

Special Citation to Harold T. Sherman

The Audio Engineering Society, by direction of the board of governors, presented a special citation to Harold T. Sherman (posthumous) "in appreciation of his contribution of time, effort, and ability, devoted to the welfare of the Society and the members it serves, and in recognition of his developments in stereophonic broadcasting."

Harold Sherman served the Society well, with enthusiasm and vigor, despite the fact that he was seriously ill and without sight for a long period of time. He was principally responsible for the interest of many radio stations in broadcasting programs simultaneously on AM and FM, and on multichannel FM, to provide stereophonic or binaural reception. He worked sincerely, without any remuneration, in this interest and in many other ways for the Society and for audio engineering generally, and for these contributions the Society presented to Mrs. Sherman this special citation for Harold T. Sherman.

Harold T. Sherman's biography appears in the January, 1953 issue of the JOURNAL (1, No. 1, p. 166). His obituary is published in the October, 1954 issue of the JOURNAL (2, No. 4, p. 262).

Special Citation to R. F. Hastings

A special citation was presented to RICHARD F. HASTINGS "for conspicuous service to the Audio Engineering Society in the promotion of its interests on the West Coast."

Harold S. Black Made Honorary Member

Honorary membership in the Audio Engineering Society was given to Harold S. Black in recognition of his contributions to the field of communications, and particularly for his work in the development of the stabilized feedback amplifier, which has been used in almost all parts of the electronic field.

In the past, those elected to honorary membership by the board of governors have been: Harvey Fletcher, Frederick V. Hunt, Vern O. Knudsen, and Edward C. Wente.

HAROLD S. BLACK was born in Leominster, Massachusetts, in 1898. He received his B.S. degree in electrical engineering from Worcester Polytechnic Institute in 1921 and at once joined what is now Bell Telephone Laboratories. In 1925 he was placed in charge of a group developing repeaters, regulators, filters, and other circuits for carrier telephone systems. In connection with his carrier research, Mr. Black invented the stabilized feedback amplifier. In 1934 Mr. Black received the AIEE prize for the best paper in theory and practice for his paper, "Stabilized Feedback Amplifiers."

From 1942 to 1947, Mr. Black was concerned almost exclusively with war developments. He also initiated and made important contributions to the early development of pulse-code modulation and the application of pulse techniques to radio communication systems. He

HAROLD S. BLACK

has recently been investigating the properties of new types of transmission lines. He is the author of a book entitled *Modulation Theory*, published by Van Nostrand in the Bell Laboratories Series.

In 1940 Mr. Black was honored by the National Association of Manufacturers as a Modern Pioneer, in recognition of distinguished achievement in the field of science and invention. He also holds the John Price Wetherill Medal of the Franklin Institute for his technical contribution to the efficiency of modern long-distance telephony. He received the Research Corporation Annual Award for Contributions to Science for 1952 in recognition of his invention and development of the negative feedback amplifier and for his general record of contributions in the field of communications.

Mr. Black is a Fellow of the AIEE and the IRE, and a member of Tau Beta Pi, Sigma Xi, and the AAAS. He holds fifty-five U. S. patents as well as numerous foreign patents, and has six additional patent applications pending.

Sixteen New Fellows Elected

Fellowship is given to "a member who has rendered conspicuous service, or is recognized to have made valuable contribution to the advancement in or dissemination of knowledge of Audio Engineering, or the promotion of its application in practice." Fellowships were awarded to:

BENJAMIN B. BAUER for his work in electroacoustics, especially in the science of microphone and headphone design.

LEO L. BERANEK for his work in electroacoustics, especially in the field of acoustical measurements.

HARRY L. BRYANT for his work in the recording and reproduction of sound, especially as it applies to the operation of a commercial recording studio.

W. ROBERT DRESSER for his work in sound recording, especially for his test records and his work on Vitarama and Cinerama.

CYRIL M. HARRIS for his research in acoustics and for his part in the authorship of one of the standard texts on acoustics.

EDWARD W. KELLOGG for his work in transducer design, especially for his work in the development of the dynamic loudspeaker and magnetic pickup.

HUGH S. KNOWLES for his research on loudspeaker design and measurement, especially as applied to the acoustic performance of loudspeakers.

HAROLD J. LEAK for his work in amplifier design, especially as applied to the development of audio amplifiers of extremely low distortion.

WALTER E. LEHNERT for his work in transformer design, especially as applied to high-quality audio transformers.

VINCENT J. LIEBLER for his work in the recording and reproduction of sound, especially as it applies to the operation of a commercial recording studio.

THEODORE LINDENBERG for his work in the recording and reproduction of sound and for his work in transducer design, development, and production.

C. G. MCPROUD for his work as editor and author, especially for the dissemination of knowledge of audio engineering.

WILLIAM H. OFFENHAUSER, JR., for his work in sound film recording, and for his work in the advancement of audio standards.

VINCENT SALMON for his work in loudspeaker design and in the design of the Hypex horn.

RALPH A. SCHLEGEL for his work in sound recording, and for his work in the advancement of recording and reproducing standards.

W. OLIVER SUMMERLIN for his work in the recording and reproduction of sound, especially as it applies to the operation of a commercial recording studio.

AES Fellows

BENJAMIN B. BAUER was graduated from Pratt Institute, where he specialized in industrial aspects of electrical engineering, in 1932 and received his E.E. degree from the University of Cincinnati in 1937.

He joined Shure Brothers, Inc., Chicago, Illinois, in 1936; he became chief engineer in 1940, director of engineering in 1944, and vice-president in 1948. For two decades, Mr. Bauer has been active in research and development in electroacoustics. He has been granted numerous patents relating to microphones, phonograph pickups, and magnetic recording, and has written extensively in technical journals on various subjects.

Mr. Bauer is a Fellow of the IRE. He was formerly national chairman of the IRE Professional Group on Audio and formerly editor-in-chief of the latter's *Transactions*. He is currently serving the IRE-PGA as secretary-treasurer. Mr. Bauer is a Fellow of the Acoustical Society of America and an associate editor of the *Journal of the Acoustical Society of America*. He is also a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

BENJAMIN B. BAUER

LEO L. BERANEK

LEO L. BERANEK received his Doctor of Science degree from Harvard University in 1940. He is currently president of the Acoustical Society of America and of Bolt, Beranek, and Newman, Inc., consultants in acoustics, and is an associate professor at the Massachusetts Institute of Technology. Mr. Beranek has written two books in the field of acoustics: *Acoustics*, published by McGraw-Hill in 1954, and *Acoustic Measurements*, published by John Wiley in 1949. He served temporarily as editor of the new magazine, *NOISE Control*.

HARRY L. BRYANT

W. ROBERT DRESSER

HARRY L. BRYANT was born in Gaffney, South Carolina, in 1909, and attended public schools there. From 1928 to 1932 he was employed by Southern Bell Telephone Company in their cable department. During this time he completed a correspondence course in radio engineering with RCA Institutes. In 1933 Mr. Bryant moved to California and for the next three years was employed in the manufacturing of public address and recording equipment by various companies. In 1936 he joined the staff of the Mutual Don Lee Broadcasting System as a studio field engineer, at the same time working in the then embryonic television department. From 1940 to 1941 he was chief engineer of the Miller Broadcasting System, and in 1941 he went to NBC as a studio and field engineer.

From 1944 to the present, Mr. Bryant has been vice-president in charge of engineering at Radio Recorders. And he is also chairman of the board and chief engineer of Picture Recorders Corporation, a new West Coast film recording company which supplies recording facilities and services to the motion picture and television industries.

Mr. Bryant is a member of the IRE and the SMPTE, and a charter member of the Sapphire Group. He has been a Western vice-president for the AES, and is program chairman, Industrial Group, of the Hollywood Chamber of Commerce.

W. ROBERT DRESSER received his B.S. in electrical communications from the Massachusetts Institute of Technology in 1927. From 1928 to 1934 he was a sound engineer with Paramount Pictures, New York City. From 1934 to date, Mr. Dresser has been the owner of the Audio-Tone Oscillator Company, makers of electronic and acoustical instruments for industrial and biophysical use. From 1937 to date he has also been affiliated with Vitarama Corporation. He was chief engineer for a Navy-operated facility (Vitarama's Waller Gunnery Trainer), and is currently vice-president in charge of Cinerama patents. From 1943 to 1953 Mr. Dresser was owner of Music by Audio-Tone, a Muzak franchise; and from 1946 to 1952 he was in charge of developing wire line and radio distribution systems for Storecast Corporation. He is presently engaged in research and undertaking graduate studies. Mr. Dresser holds forty patents and has forty-four additional applications on file in the U. S. and foreign patent offices. He is a senior member of the IRE, an active member of the SMPTE, and a member of the Acoustical Society of America, the Instrument Society of America, and the American Institute of Physics.

CYRIL M. HARRIS was born in Detroit, Michigan, in 1917. He received a B.A. degree in mathematics (1938) and an M.A. degree in physics (1940) from the University of California at Los Angeles, and his Ph.D. in physics in 1945 from the Massachusetts Institute of Technology.

He was on the teaching staff at the University of California at Los Angeles, 1939–1940. In 1941 he was affiliated with the Carnegie Institution of Washington and did war research work at the Massachusetts Institute of Technology, Bemis Foundation; for three years after that, he did war research work under contract with the Office of Scientific Research and Development at M.I.T., and from 1943 to 1945 he was on the M.I.T. teaching staff. From 1945 to 1951 he was a member of the technical staff, Bell Telephone Laboratories. In 1951 he was a scientific consultant, Office of Naval Research, London Branch, England; in 1951-1952 he was a Visiting Fulbright Lecturer at the Technical University at Delft, The Netherlands. Since 1952 he has been Director of the Acoustics Laboratory and associate professor of electrical engineering at Columbia University.

Mr. Harris is a member of the Physical Society of London, Acoustics Group, Sigma Xi, and Tau Beta Pi; a senior member of the IRE; and a Fellow of the Acoustical Society of America. He is coauthor with V. O. Knudsen of *Acoustical Designing in Architecture*, and is editor of a new *Handbook of Noise Control*, now in preparation, to be published by McGraw-Hill Book Company. He has also written numerous scientific articles.

HUGH S. KNOWLES received his B.A. degree from Columbia University in 1928. He did graduate work at the University of Chicago from 1930 to 1933 and was a guest lecturer in graduate physics from 1935 to 1936. He was chief engineer at the Jensen Manufacturing Company from 1930 to 1940, serving also as vice-president. He has been a consulting engineer since 1936.

Mr. Knowles has been president and director of research for Industrial Research Products since 1946 and has held the same positions for Knowles Electronics, Inc., since 1954. An active participant in various societies in the fields of physics and acoustics, he has been a member of the governing board of the American Institute of Physics since 1951, and a member of the executive committee since 1954; past

CYRIL M. HARRIS

HUGH KNOWLES

president of the Acoustical Society of America; past president of the Chicago Radio Engineers Club. He is a Fellow of the IRE, and is a past chairman of the Chicago Section of the IRE as well as past chairman of the latter's committee on electroacoustics. In addition, he has been chairman of the standards committee on sound equipment and chairman of the sound equipment section of the RETMA. Mr. Knowles has also contributed his services to the government, as chairman of the Acoustics Panel, Research and Development Board, Office of the Secretary of Defense, from 1948 to 1950, and as a member of the executive committee of the Physical Science Division of the National Research Council (1951–1952). As an author, he has contributed sections on audio and electroacoustics to the John Wiley Handbook Series and to Henney's *Radio Engineering Handbook*.

WALTER E. LEHNERT's biography appears in the January, 1953, issue of the JOURNAL (1, No. 1, p. 166).

VINCENT J. LIEBLER

VINCENT SALMON

VINCENT J. LIEBLER was born October 6, 1904, in Brooklyn, New York. He attended schools in New York and in 1926 was graduated from Pratt Institute, Brooklyn, where he majored in electrical engineering. He was employed as electrical inspector for the Long Island Railroad, assigned to the development and installation of automatic train control systems from 1926 to 1928.

In 1928 Mr. Liebler joined the Brunswick Record Company as recording engineer, assigned to equipment maintenance and studio operation. He spent the years of 1929 to 1930 on portable recording assignments in Europe and the West Indies. On his return from Europe, he was assigned to Warner Brothers Picture Studios as sound engineer on film until 1932.

In 1932 he joined the American Record Company as assistant chief recording engineer, after the Brunswick Record Company was sold to them, and became chief recording engineer of the combined American-Brunswick-Columbia Record Company in 1935. In 1939, after the combined companies were purchased by the Columbia Broadcasting System, he became director of recording operations for Columbia Records, Inc., the position he now holds. During this period he has assisted in the design and construction of the original and subsequent Columbia Records, Inc., recording laboratories and facilities in New York, Chicago, and Hollywood, and has continued directing the maintenance of these units.

THEODORE LINDENBERG's biography appears in the October, 1953, issue of the JOURNAL (1, No. 4, p. 332).

C. G. MCPROUD's biography appears in the October, 1953, issue of the JOURNAL (1, No. 4, p. 327).

W. H. OFFENHAUSER, JR.'s biography appears in the January, 1954, issue of the JOURNAL (2, No. 1, p. 63).

VINCENT SALMON received his B.A. and M.A. degrees in physics from Temple University in 1934 and 1936, respectively, and his Ph.D. in theoretical physics from M.I.T. in 1938. From 1939 to 1949 he was a physicist with the Jensen Manufacturing Company, in charge of research and development. Since 1949 Mr. Salmon has been manager of the Sonics Section, Physical Sciences Division, Stanford Research Institute. He has specialized in electroacoustics, loudspeakers, horns, industrial acoustics, noise reduction, and studio acoustics. His interest in sound recording has led him to operate a tape- and disc-recording service in his spare time.

Mr. Salmon is a Fellow of the AES and the Acoustical Society of America, a senior member of the IRE, a member of the Golden Gate Sapphire Club, and a member of the Research Society of America. He has acted as chairman of the RETMA committee on loudspeakers (1949–1950) and is currently chairman of the IRE professional group on audio. In 1946 he was presented with the Biennial Award of the Acoustical Society of America. At present, Mr. Salmon is editor of the JOURNAL OF THE AUDIO ENGINEERING SOCIETY. He has acted as an editorial reviewer for the IRE, as patent reviewer for the Acoustical Society of America, and as reviewer for *Applied Mechanics Reviews*.

W. OLIVER SUMMERLIN

W. OLIVER SUMMERLIN was born in Mount Olive, North Carolina, in 1918. He attended Mars Hill College, Mars Hill, North Carolina, and was graduated from the Radio Engineering Course of RCA Institutes in 1938. After four years of communication and broadcast engineering, Mr. Summerlin spent three and one-half years as a radar engineering officer with the U. S. Naval Reserve. Since then he has served successively as chief recording engineer for Capitol Records, Inc., in New York City; as vice-president for engineering of Audio and Video Products Corporation; and, during the past two years, as president of Pulse Techniques, Inc., West Englewood, New Jersey. Mr. Summerlin is a charter member of the AES and has served on the Board of Governors.

Program of Technical Sessions

Thursday Morning—October 14, 1954

ANNUAL MEETING OF THE AUDIO ENGINEERING SOCIETY—9:30 A.M.

MICROPHONES—10:00 A.M.–12:00 NOON

Chairman: B. B. Bauer
Shure Brothers, Inc., Chicago, Ill.

CATHODE FOLLOWER CIRCUITS APPLIED TO A MICROPHONE
John K. Hilliard and James J. Noble, Altec Lansing Corp., Beverly Hills, Calif.

The cathode-follower vacuum tube is used as an impedance translator between the miniature condenser microphone and the output circuits. It is evaluated in this paper for both the triode and pentode connection and it is shown that the pentode connection is the most favorable in terms of input admittance. A means for minimizing noise arising from thermal agitation and leakage current is presented with data relating the noise threshold to the real component of the microphone circuit impedance.

MICROPHONES FOR INFORMAL USE
L. M. Wigington and R. M. Carrell, RCA Electronic Products Division, Camden, N. J.

Present-day television audio technique often requires that a small microphone be placed near the performer or even be worn by him. The mechanical and acoustical requirements of such a microphone differ from those of a conventional dialogue microphone. Real voice measurements employing an integrating audiospectrometer are used to indicate the nature of the frequency response characteristic required by a chest microphone to provide a normal over-all balance. Some marked variations in the speech spectra at different points on the chest are observed. The new RCA BK-6A microphone is designed especially for use as a chest microphone. It is intended for "informal," "off-mike" use as contrasted with the "formal" manner of address customary with microphones of the type common in AM broadcasting and in recording practice.

UNIAXIAL MICROPHONES
Harry F. Olson, John Preston and J. C. Bleazey, RCA Laboratories, Princeton, N. J.

Uniaxial microphones are unidirectional microphones in which the maximum response occurs on the principal cylindrical axis. Ribbon transducers are used in these microphones, say the authors, because of the outstanding and desirable characteristics of these systems as demonstrated in more than two decades of use. Distributed and lumped acoustical resistance terminations and phase-shifting networks have been developed for uniaxial microphones. Uniaxial microphones of both first and second order have been developed.

A STABLE LABORATORY STANDARD CONDENSER MICROPHONE
Joseph F. Houdek, Jr., Kellogg Switchboard & Supply Co., Chicago, Ill.

This paper appears in the October, 1954 issue of the JOURNAL *(2, No. 4, pp. 234–238).*

A METHOD FOR QUANTITATIVE MEASUREMENT OF WIND NOISE SENSITIVITY IN MICROPHONES
R. M. Carrell, RCA Electronic Products Division, Camden, N. J.

A long, spring-suspended pendulum is presented as a simple means of making quantitative measurements of the wind noise sensitivity of microphones. Measurements of the velocity-displacement characteristics of a typical pendulum of this type are presented.

MISCELLANEOUS SUBJECTS INCLUDING TAPE MACHINES—2:00–4:30 P.M.

Chairman: Sherman M. Fairchild
Fairchild Recording Equipment Corp.

A MOVING COIL FEEDBACK DISK RECORDER
C. C. Davis, Westrex Corporation, Hollywood, Calif.

This paper appears in full in the October, 1954 issue of the JOURNAL *(2, No. 4, pp. 228–233).*

AN EXTERNAL AUTOMATIC SWEEP GENERATOR FOR USE WITH CATHODE RAY OSCILLOSCOPES
Alan Bloch, Audio Instrument Co., Inc., New York City

This paper appears in full in the October, 1954 issue of the JOURNAL *(2, No. 4, pp. 259–261).*

AN EXPERIMENTAL STUDY OF DISTORTION
C. J. LeBel, Audio Instrument Co., Inc., New York City

This paper appears in full in the October, 1954 issue of the JOURNAL *(2, No. 4, pp. 215–218).*

TRANSISTORIZED MAGNETIC TAPE RECORDER
A. I. Aronson, RCA Engineering Products Division, Camden, N. J.

An experimental transistorized record-playback tape recorder is described. The author claims performance characteristics equal to, or better than, those of conventional recorders. Direct coupling to the loudspeaker and utilization of the tape drive motor as a power transformer is said to eliminate the need for costly and bulky iron-cored components. The amplifier stages are stabilized for both temperature change and transistor variation.

DEVELOPMENT OF A SUBMINIATURE TAPE RECORDER
Albert C. Travis, Jr., Broadcast Equipment Specialties Corp., Beacon, N. Y.

This paper covers the problems and solutions involved in scaling down the transport and amplifier to pocket size; the author's goal was to avoid undue sacrifice of functions, recording time, or quality, while at the same time, using as many readily available components as possible. The resulting unit, the Tapette, which is as small as the Minifon wire recorder, is described.

DEFINITE STEREOPHONIC SOUND
R. H. Ranger, Rangertone, Inc., Newark, N. J.

The illusion of perspective in sound perception is obtained by presenting to the two ears of each auditor a differential impression of the sound to simulate localized sources. A reflector, in the form of a cylinder of thin metal, serves to direct the sound from two speakers located on each side of the cylinder. Because it is a convex reflector, the intensity and phase differential is maintained quite well over the auditorium. The test for the effectiveness with which this condition is achieved is that, with equal audio drives on the speakers on each side, the apparent location of the sound appears to be in the center of the reflector for all positions in the auditorium.

Friday—October 15, 1954

TAPE MEDIA—10:00 A.M.-12:00 NOON

Chairman: Richard H. Ranger
Rangertone, Inc., Newark, N. J.

FREQUENCY MODULATION NOISE IN MAGNETIC RECORDING
R. A. von Behren and R. J. Youngquist, Minnesota Mining & Manufacturing Co., St. Paul, Minn.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

MAGNETIC RECORDING MEASUREMENTS
Walter H. Erickson, RCA Victor Division, Camden, N. J.

The current need for measurement standardization in magnetic recording is discussed. Problems associated with measurement of frequency response, nonlinear distortion, recorded level, noise, modulation noise, layer-to-layer "print-through", crosstalk, erase efficiency, and tape speed are evaluated with respect to the question of systems standardization.

DEFECTS IN MAGNETIC RECORDING TAPE: THEIR CAUSE AND CURE
Frank Radocy, Audio Devices, Inc., New York City

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

LOCATING DEFECTS IN MAGNETIC RECORDING TAPE
Andreas Kramer, Audio Devices, Inc., Glenbrook, Conn.

Since the application of magnetic recording tape to the more critical types of recording, new tape testing methods have become necessary. This paper describes an instrument for making instantaneous uniformity-of-response tests by locating and registering the number of individual cycles of output voltage that are below a pre-set level. In precision tape today, explains the author, "dropouts" are due almost entirely to extraneous matter on the surface; two years ago, physical imperfections in the tape coating tended to cause most of the difficulties.

NEW USES AND NEW MAGNETIC PRODUCTS IN TAPE, FILM, AND INSTRUMENTATION APPLICATIONS DURING THE PAST TWO YEARS
E. W. Franck and E. Schmidt, Reeves Soundcraft Corp., Springdale, Conn.

In the last two years, advances in the manufacture and application of magnetic products have been made. This paper covers the physical and electrical characteristics of current standard tapes and Mylar tapes of various gauges. Level differences between forward recording and reverse recording are discussed and a report is given on "print-through" characteristics of materials coated on base supports as thin as 0.5-mil Mylar. The use of striped magnetic film in motion pictures and in television is dealt with as is the use of magnetic products for geophysical recording. Discussed, too, are strides which have been made in improving the friction characteristics of tape and film: These improvements, claim the authors, have solved some of the problems associated with telemetering and other instrumentation applications. The characteristics of lubricated recording materials are set forth.

RECORDS & RECORD MANUFACTURING—2:00–4:30 P.M.

Chairman: Charles Lauda
Decca Records

QUALITY CONTROL IN RECORD MANUFACTURING
E. H. Uecke, Capitol Records, Inc., Hollywood, Calif.

This paper covers test and inspection procedures, from lacquer masters through the finished product: Methods and procedures developed to check adherence to specifications; processing controls; material acceptance inspection; and quality audit of the finished records. Consideration is given to the selection of those inspection points which best permit the exercise of the required degree of control.

RECORD QUALITY AND ITS RELATION TO MANUFACTURING
A. M. Max, RCA Victor Record Division, RCA, Indianapolis, Ind.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

ADVANTAGES AND PROBLEMS OF FULL-FREQUENCY RANGE PHONOGRAPH REPRODUCTION
Paul Weathers, Weathers Industries, Inc., Barrington, N. J.

Ten years ago, declares the author, anyone suggesting that a phonograph-record reproducing system could extend beyond the 6,000- or 7,000-cps point was looked upon as a dreamer. The advent of high fidelity in more and more homes, with studio programs available on FM stations, has made the public increasingly critical. Today, according to the author, no high-fidelity enthusiast is happy with phonograph reproduction which does not extend to 15,000 cps at the high end and 30 cps at the low end. The difficulties entailed in recording so extended a range are many and varied. By the same token, the problems of *reproducing* such a range are felt to be even greater. The author regards an extended range as indispensable in the reproduction of transient sounds. The problems involved in reproducing this range without increasing objectionable distortion and noise are discussed.

AN EVALUATION OF RECORD STYLUS PRESSURE CALCULATIONS
A. M. Max, RCA Victor Record Division, Indianapolis, Ind.

The classical theory of elasticity predicts that fine-groove records are impossible. It predicts stresses in the records in excess of the ultimate strength of the record material. It is known that the classical theory of elasticity falls far short in describing the mechanical properties of plastics. These properties are described along with a qualitative evaluation of their effect on the stresses produced by the stylus.

SPECULATIONS ON THE CAUSE AND PREVENTION OF NEEDLE WEAR AND SURFACE NOISE IN THE PHONOGRAPH PLAYBACK PROCESS
F. V. Hunt, Acoustics Research Laboratory, Harvard University

This paper is published in the present issue of the JOURNAL *under the title "On Stylus Wear and Surface Noise in Phonograph Playback Systems." See Table of Contents.*

Saturday—October 16, 1954

PICKUPS—10:00 A.M.–12:00 NOON

Chairman: Norman C. Pickering
Pickering & Co., Oceanside, N. Y.

A DISCUSSION OF PRESENT-DAY DEVELOPMENTS IN MAGNETIC PHONOGRAPH PICKUPS
Walter O. Stanton, Pickering & Co., Oceanside, N. Y.

The author compares the electrical signal generated by the pickup with the mechanical motion of the cutting stylus and discusses the inherent relationship between the two. The author points out that the magnetic pickup does not, of itself, require equalization, but, rather, that compensation is needed in the playback circuit to secure a response characteristic which is the conjugate of the equalization inserted in the recording channel ahead of the magnetic cutter. In the second part of this paper, the author attempts to correlate lateral mechanical impedance with the over-all tracking capabilities and performance of the modern high-quality pickup.

A TWIN-LEVER CERAMIC CARTRIDGE
B. B. Bauer, L. Gunter, Jr., and E. Seeler, Shure Brothers, Inc., Chicago, Ill.

This paper appears in the October, 1954 issue of the JOURNAL *(2, No. 4, pp. 239–243).*

AMPLIFIERS FOR MUSIC REPRODUCTION
Hermon H. Scott and Herbert P. Kent, Hermon Hosmer Scott, Inc., Cambridge, Mass.

The classical concept of the measurement of amplifiers with con-

tinuous sine-wave signals does not apply rigorously to amplifiers designed for the high-fidelity reproduction of music. Usually the designer must choose between providing either maximum instantaneous short-time output or maximum continuous sine-wave output; since the usual musical waveform is complex, having peaks 10 or more db higher than the average level, it is obvious that the former condition is best for the reproduction of music. With higher powered amplifiers, the maximum available continuous power can actually burn out the loudspeaker on a continuous overload. A "snubber" circuit has been developed, say the authors, that does not affect the power-handling capacity of the amplifier on music waveforms but which protects the loudspeaker from continuous high power levels. By this means, high-powered amplifiers can provide maximum realism on peak music levels without the usual danger of speaker burnout. Such a device can be adjusted by the user to provide any degree of "snubbing" action. An important consideration with respect to amplifiers, much misunderstood, is the internal output impedance or damping factor. Many amplifiers have output impedances approaching zero, while actually most loudspeaker manufacturers recommend a finite source impedance of a magnitude which may be as high as the rated speaker impedance. A system is described which, while providing adjustable output impedance without adversely affecting amplifier performance, allows optimum damping for all types of loudspeakers.

Loudspeaker Quality Control and the Consumer

Edward V. Reiss, University Loudspeakers, Inc., White Plains, N. Y.

The consumer's investment in a loudspeaker is protected by the design considerations built into the speaker and by the production checks employed in its fabrication, declares the author. This paper examines the aforementioned design fundamentals which, while not superficially visible, nevertheless contribute to the longevity and the durability of the loudspeaker. The author also presents various production tests and checks designed to guarantee uniform performance and consistent quality in the final product.

Correlation of Transient Measurements on Loudspeakers and Listening Tests

Murlan S. Corrington, RCA Victor Television Division, RCA, Camden, N. J.

This paper appears in full in the present issue of the Journal. *See Table of Contents.*

LOUDSPEAKERS—1:30–4:30 P.M.

Chairman: Hugh S. Knowles
Industrial Research Products, Franklin Park, Ill.

A Twenty-Inch Corner Horn of Unusual Design

Paul Klipsch, Klipsch & Associates, Hope, Ark.

A study was undertaken in 1954 to devise an enclosure 20 to 24 in. high, in conformance with Klipsch corner-horn principles, for very small speakers. The result was a corner-horn design called the "Rebel V." Although crowding results, says the author, it is possible to use a separate three-way system with a 12-in. "woofer", with crossover points at 1,000 and 5,000 cps. The design is not intended to give a great, powerful, boomy bass, nor to approach the tonal response of a Klipschorn, explains the author, but rather to yield a response as smooth as possible in terms of the imposed space limitations and as free from distortion as possible, considering the necessarily high crossover frequencies used.

Acoustical Calibration of Loudspeakers at Higher Frequencies

John K. Hilliard, Altec Lansing Corp., Beverly Hills, Calif.

This paper outlines techniques used to calibrate the free-field response of a loudspeaker in the higher frequency range. The specific apparatus used and the results obtained are discussed. Several microphones and loudspeakers which are reversible transducers are described.

Recent Developments in High-Fidelity Loudspeakers

Harry F. Olson, John Preston, and Everett G. May, RCA Laboratories, Princeton, N. J.

This paper appears in full in the October, 1954 issue of the Journal (*2, No. 4, pp. 219–227*).

An Electrostatic Loudspeaker Development

Arthur A. Janszen, Engineering Consultant, Cambridge, Mass.

The author describes an electrostatic loudspeaker designed for use with two-way systems. High efficiency from below 1,000 cps to above 20 kcs is claimed. The membrane used in the building-block elements of the unit is so light, says the author, that, over most of the frequency range, it functions essentially as an imaginary boundary in the air. The axial pressure response is said to be extremely smooth. The loudspeaker operates from the 8-ohm or 16-ohm tap of any power amplifier and incorporates its own bias supply.

Multicrossover, Multi-impedance Networks for Compatible Multispeaker Systems

Abraham B. Cohen, University Loudspeakers, Inc., White Plains, N. Y.

This paper is published in the present issue of the Journal *under the title "Multi-impedance, Multifrequency Crossover Networks for Multispeaker Systems." See Table of Contents.*

High Efficiency Three-Way Speaker System

Saul J. White, University Loudspeakers, Inc., White Plains, N. Y.

With improvement in response characteristics of "extended range" single loudspeakers, the question of the advantages of multichannel systems—particularly for home use—has been raised. This paper presents the author's arguments in favor of multichannel systems, and describes a specific triple-range system consisting of a folded-horn woofer and horn-type mid-range and tweeter units, all of the indirect radiator type. Making up the entire system of compression-type, horn-loaded units, claims the author, results in a substantial improvement in efficiency, reduction of distortion and extension of the overall response. Demonstration of an integrated system of acceptable dimensions for home use accompanies this paper.

Exhibitors at Audiorama 1954, New York

Following are the companies which participated in Audiorama 1954. Listed, too, are their products.

Acoustic Research, Inc.
23 Mt. Auburn St., Cambridge 38, Mass.
Loudspeaker systems.

Acro Products Co.
369 Shurs La., Philadelphia 28, Penna.
Transformers.

Allegro Electronics Corp.
226 New York Ave., Huntington, N. Y.
Phonographs; AM-FM phonograph combination; tape recorder consoles.

Alpha Wire Corporation
430 Broadway, New York 13, N. Y.
Wire and cable for electronic applications.

Altec Lansing Corp.
161 Sixth Ave., New York 13, N. Y.
Loudspeakers; condenser microphones; loudspeaker enclosures; accessories; semi-assembled systems for hi-fi novices.

American Elite, Inc.
1775 Broadway, New York 19, N. Y.
Condenser microphones; radio sets; table models; portables; record changers; tape recorders.

AMI Incorporated
1500 Union Ave., S. E., Grand Rapids 2, Mich.
Juke boxes.

Ampex Corporation
934 Charter St., Redwood City, Calif.
Magnetic tape recorders; speaker-amplifier combinations.

Ampro Tape Recorders
2835 N. Western Ave., Chicago 18, Ill.
Tape recorders; phonographs.

Angle Genesee Corp.
107 Norris Drive, Rochester 10, N. Y.
Cabinetry for audio installations; loudspeaker enclosures.

A. R. F. Products, Inc.
7627 Lake St., River Forest, Ill.
Unit featuring an electrostatic speaker and FM tuner.

Asco Sound Corporation
115 West 45th St., New York 36, N. Y.
Home music systems; sound systems for schools, churches, industry. Tape recorder sales and service. Consulting and engineering services.

Audak Company
500 Fifth Ave., New York 36, N. Y.
Audio equipment; pickups.

Audio Devices, Inc.
444 Madison Ave., New York 22, N. Y.
Tape in color, on colored reels. Tape on standard base and on Mylar polyester base for instrumentation purposes; magnetic film for motion-picture applications; recording discs; phonograph needles and styli.

The Audio Exchange, Inc.
159-19 Hillside Ave., Jamaica 32, N. Y.
Distributors for many manufacturers; this firm buys, sells, and trades new and used components; manufactures foam-rubber turntable discs.

Audio & Video Products Corp.
730 Fifth Ave., New York 19, N. Y.
Tape recorders and accessory equipment; audio equipment.

Audiogersh Corp.
254 Grand Ave., New Haven 13, Conn.
Record changers; record players; accessories.

A-V Tape Libraries, Inc.
730 Fifth Ave., New York 19, N. Y.
Recorded tapes (popular and classical music, educational, literary, and religious material recorded on magnetic tape); background music on long-playing tapes for stores, restaurants, offices, factories.

Beam Instruments Corp.
350 Fifth Ave., New York 1, N. Y.
Loudspeakers; amplifiers; enclosures.

Bell Sound Systems, Inc.
555 Marion Road, Columbus 7, Ohio
Amplifiers; remote-control amplifiers; two-channel amplifiers; loudspeakers; tape recorders; tape playback units; radio tuners.

Berlant Associates
4917 West Jefferson Blvd., Los Angeles 16, Calif.
Single-channel and multichannel tape recorders; accessories.

David Bogen Co., Inc.
29 Ninth Ave., New York 14, N. Y.
Amplifiers; AM, FM, and combination AM-FM tuners; AM-FM receivers; equalizers; loudness-contour controls; transcription players; radio console cabinets; intercoms.

The R. T. Bozak Company
114 Manhattan St., Stamford, Conn.
Loudspeakers; baffles.

British Industries Corp.
164 Duane St., New York 13, N. Y.
Distributors: record changers; phonograph equipment; amplifiers; loudspeakers; enclosures; turntable mats; tape recorder heads.

Brociner Electronics Laboratory
344 E. 32nd St., New York 16, N. Y.
Amplifiers; preamplifier-equalizers; corner horns.

Browning Laboratories, Inc.
750 Main St., Winchester, Mass.
FM tuners; AM-FM tuners; two-channel tuners.

Capehart-Farnsworth Company
3700 E. Pontiac, Fort Wayne 1, Ind.
Radio-phonograph combinations.

Capitol Records, Inc.
1730 Broadway, New York 19, N. Y.
Phonograph records.

Frank L. Capps & Co., Inc.
20 Addison Place, Valley Stream, N. Y.
Condenser and dynamic microphones; disc recording styli.

Columbia Records, Inc.
799 Seventh Ave., New York 19, N. Y.
Phonograph records; phonographs.

Conrac, Inc.
19217 E. Foothill Blvd., Glendora, Calif.
Custom television chassis; remote-control units.

Cook Laboratories, Inc.
114 Manhattan St., Stamford, Conn.
Preamplifiers; test records; LP and two-channel records.

Cowan Publishing Corp.
67 W. 44th St., New York 36, N. Y.
Publishers: *Radio-TV Service Dealer and CQ, The Radio Amateurs' Journal* (*magazines*); *Video Speed Servicing Systems; Radio Amateurs' Mobile Handbook; Single-Sideband Techniques* (*handbooks*).

Daystrom Electric Corp.
Crestwood Recorder Division
753 Main St., Poughkeepsie, N. Y.
Magnetic tape recorders.

DeMars Engineering & Mfg. Co.
360 Merrimack St., Lawrence, Mass.
Loudspeaker systems.

Dictograph Products, Inc.
Hi-Fidelity Music Division
95-25 149th St., Jamaica 35, N. Y.
Home music systems.

Electro-Sonic Laboratories
35-54 36th St., Long Island City 6, N. Y.
Phonograph pickups; matching transformers; preamplifiers.

Electro-Voice, Inc.
Cecil and Carroll Sts., Buchanan, Mich.
Crystal and ceramic phonograph pickups and cartridges; microphones; loudspeakers; driver units; cellular and diffraction horns; crossover networks; speaker enclosures; FM and television boosters; preamplifiers; amplifiers; equipment consoles.

Espey Mfg. Co., Inc.
528 E. 72nd St., New York 21, N. Y.
AM-FM tuners, receivers and amplifiers; phonographs; playback equipment; two-channel reproducers and tuners.

Fairchild Recording Equipment Co.
Whitestone 57, N. Y.
Moving-coil cartridges and accessories; plug-in transcription arms; turret-head transcription arms; preamplifier-equalizers.

Federal Manufacturing & Engineering Corp.
211 Steuben St., Brooklyn 5, N. Y.
Tape recorders and accessories.

Federated Electronics Sales, Inc.
66 Dey St., New York 7, N. Y.
Distributors: audio equipment.

Fenton Company
15 Moore St., New York 4, N. Y.
Tape recorders; record changers; remote-control hearing aids for television; pillow speakers; miniature earsets; uhf converters; vhf boosters.

Ferranti Electric, Inc.
30 Rockefeller Plaza, New York 20, N. Y.
Phonograph pickups.

Fisher Radio Corp.
21-21 44th Drive, Long Island City 1, N. Y.
Amplifiers; audio-control units; filters; horns; phonograph cartridges; preamplifiers; preamplifier-equalizers; AM-FM tuners.

Freed Electronics & Controls Corp.
200 Hudson St., New York 13, N. Y.
Tuners; amplifiers; receivers.

Gates Radio Company
123 Hampshire St., Quincy, Ill.
Broadcast audio equipment and control consoles for television broadcasting, and recording; three-channel remote amplifiers; three-speed turntables.

General Electric Company
RTVD #5, Electronics Park, Syracuse, N. Y.
Variable-reluctance pickups; preamplifier-equalizers; audio equipment.

G & H Wood Products Co. (Cabinart)
75 N. 11th St., Brooklyn 11, N. Y.
Loudspeaker enclosures; equipment cabinets.

Goodmans Industries Limited
215 E. 37th St., New York 16, N. Y.
Loudspeakers.

Harold Gordon Agencies
1506 North Western Ave., Hollywood 27, Calif.
Loudspeakers.

Gray Research & Development Co., Inc.
658 Hilliard St., Manchester, Conn.
Audio equipment for home and broadcast use; transcription arms; equalizers.

Grommes
Div. of Precision Electronics, Inc.
9101 King Ave., Franklin Park, Ill.
Amplifiers.

Adolph L. Gross Associates, Inc.
23 Park Place, New York 7, N. Y.
Record changers; record players.

Hack Swain Productions
AAA-Carey Bldg., Box 2384, Sarasota, Fla.
Recorded tapes.

Harman-Kardon, Inc.
52 W. Houston St., New York 12, N. Y.
AM-FM tuners; amplifiers; combination AM-FM tuner - amplifier - power - amplifier units.

Harrison High Fidelity Record Catalog & Record (and Sound) Retailing
274 Madison Ave., New York 10, N. Y.
Publishers: record catolog; *Record (and Sound) Retailing*.

Harvey Radio Company, Inc.
103 W. 43rd St., New York 36, N. Y.
Distributors: home music systems and components; tape recorders, radio parts, and broadcast supplies.

Hastings Products, Inc.
171 Newbury St., Boston 16, Mass.
FM car radios.

Haydn Society, Inc.
30 Huntington Ave., Boston, Mass.
Phonograph records.

Haynes-Griffin, Ltd.
420 Madison Ave., New York, N. Y.
Phonograph records; three-speed phonographs.

High Fidelity Magazine
The Publishing House, Great Barrington, Mass.
Publishers: *High Fidelity Magazine*.

Interelectronics Corp.
2432 Grand Concourse, New York 58, N. Y.
Amplifier; "consolette" with provisions for fm pickup and audio amplifier for motion picture projector.

International Electronics Corp.
147 Parkhouse St., Dallas, Texas
Loudspeakers for home music systems, electronic organs and theatres.

International Scientific Industries Corp.
3101 42nd St., Minneapolis 6, Minn.
Tape recorders.

Jensen Manufacturing Co.
6601 S. Laramie Ave., Chicago 38, Ill.
Loudspeakers; cabinets.

Karlson Associates, Inc.
1483 Coney Island Ave., Brooklyn 30, N.Y.
Enclosures.

Klipsch & Associates
P. O. Box 64, Hope, Arkansas
Corner-horn loudspeakers.

Kral Products
1704 Walnut St., Philadelphia 3, Penna.
Record brush.

Laboratory of Electronic Engineering
413 L Street, N. W., Washington 1, D. C.
Loudspeakers; medical electronic equipment; instrumentation.

Langevin Manufacturing Corp.
37 W. 65th St., New York 23, N. Y.
Amplifiers; power supplies; transformers; reactors.

James B. Lansing Sound, Inc.
2439 Fletcher Drive, Los Angeles 39, Calif.
Loudspeakers.

Leonard Radio, Inc.
69 Cortlandt St., New York 7, N. Y.
Distributors: sound equipment; record players; tuners; amplifiers; speakers; cabinets; tapes; records.

Leru Laboratories, Inc.
Black Oak Ridge Road, Wayne, N. J.
Imported radios and phonographs; single packaged AM-FM-short-wave tuners with audio amplifiers and speakers.

London Records, Inc.
539 W. 25th St., New York 1, N. Y.
Phonograph records.

The Magnavox Company
Fort Wayne 4, Indiana
Radios; phonographs; radio-phonographs; television sets; television-radio-phonograph combinations.

Magnecord, Inc.
225 W. Ohio St., Chicago 10, Ill.
Tape recording systems for professional and home use.

The Maico Co., Inc.
21 N. Third St., Minneapolis 1, Minn.
Audio-frequency curve tracers; hearing aids; audiometers; psychometers; sound spectrographs; auditory training systems.

Majestic International Corp.
Subsidiary of The Wilcox-Gay Corp.
79 Washington St., Brooklyn 1, N. Y.
Pocket radios; AM-FM, short-wave, long-wave radios and radio-phonograph combinations; tape recorders.

S. B. Marantz
25 W. 43rd St., New York 36, N. Y.
Control preamplifier-equalizers.

Marine View Electronics, Inc.
744 E. 138th St., New York 54, N. Y.
Tuners; amplifiers; preamplifiers.

Jeff Markell Associates
764 Sixth Ave., New York 10, N. Y.
Equipment cabinets and loudspeaker enclosures for home systems.

McIntosh Laboratory Inc.
320 Water St., Binghamton, N. Y.
Amplifiers.

Mercury Record Corp.
35 East Wacker Drive, Chicago 1, Ill.
Phonograph records.

Minnesota Mining and Manufacturing Co.
900 Fauquier Ave., St. Paul 6, Minn.
Magnetic recording tapes and accessory items.

Mooney-Rowan Publications
Severna Park, Maryland
Publishers: *Tape Recording Magazine; The Sound Salesman; Audio Industry Directory,*

Motorola, Inc.
4545 W. Augusta Blvd., Chicago 51, Ill.
Phonographs; car radios; AM, FM, television equipment.

Motorola-New York, Inc.
29-30 Hunters Point Ave., Long Island City 1, N. Y.
Tape recorders; phonographs.

Music Age, Inc.
Route 4, Paramus, N. J.
Distributors: audio components.

Music at Home
207 E. 37th St., New York 16, N. Y.
Publishers: *Music at Home Magazine;* books.

National Company, Inc.
61 Sherman St., Malden 48, Mass.
AM-FM tuners; audio amplifiers; preamplifier-control units.

Newcomb Audio Products Co.
6824 Lexington Ave., Hollywood 38, Calif.
Amplifiers; AM-FM tuners; phonographs; transcription players; public address equipment.

Orradio Industries, Inc.
T-120 Marvyn Road, Opelika, Alabama
Standard and Mylar-base recording tape; tape recording accessories.

The Pentron Corp.
777 S. Tripp Ave., Chicago 24, Ill.
Professional and portable tape recorders; tape recording components for custom installations and portable use; accessories.

Permoflux Corp.
4900 W. Grand Ave., Chicago 39, Ill.
Loudspeakers and loudspeaker systems; headphones; tweeters; crossover networks.

Pickering and Company, Inc.
309 Woods Ave., Oceanside, N. Y.
Magnetic cartridges; pickup arms; equalizers; preamplifiers; equalizer-preamplifiers.

Pilot Radio Corp.
37-06 36th St., Long Island City 1, N. Y.
Amplifiers; premaplifiers; AM-FM and FM tuners; portable phonographs; remote-control television chassis.

Presto Recording Corp.
P.O. Box 500, Paramus, N. J.
Disc and tape recording and reproducing equipment; lacquer-coated aluminum blank recording discs.

Radio Corporation of America
Front and Cooper Sts., Camden 2, N. J.
Phonographs; phonograph records; audio components.

The Radio Craftsmen, Inc.
4401 N. Ravenswood Ave., Chicago 40, Ill.
Preamplifiers; amplifiers; AM-FM tuners.

Radio-Electronics
25 W. Broadway, New York 7, N. Y.
Publishers: *Radio-Electronics Magazine;* magazines and books.

Radio Magazines, Inc.
204 Front St., Mineola, N. Y.
Publishers: *Audio Magazine; First Audio Anthology; Second Audio Anthology;* books.

Radio Station WQXR
229 W. 43rd St., New York 36, N. Y.
Radio station; AM and FM broadcasts; two-channel stereophonic transmissions.

Radio & Television News
366 Madison Ave., New York 17, N. Y.
Publishers: *Radio and Television News.*

Radio Wire Television, Inc.
(Lafayette Radio)
100 Sixth Ave., New York 13, N. Y.
Amplifiers; tuners; loudspeakers; recorders.

Reeves Soundcraft Corp.
10 E. 52nd St., New York 22, N. Y.
Magnetic recording materials: quarter-inch tape; oxide-coated motion-picture film.

Regency Division—I.D.E.A., Inc.
7900 Pendleton Pike, Indianapolis 26, Ind.
Amplifiers; FM-AM tuners.

Rek-O-Kut Company
38-01 Queens Blvd., Long Island City 1, N. Y.
Turntables; disc recorders; recording amplifiers; portable p.a.-phonograph combinations with three-speed arrangements and with continuously-variable speed control; studio consoles.

Revere Camera Company
320 E. 21st St., Chicago 16, Ill.
Tape recorders.

John F. Rider Publisher, Inc.
480 Canal St., New York 13, N. Y.
Publishers: service manuals, books.

Rockbar Corporation
215 E. 37th St., New York 16, N. Y.
Record changers; players; crystal pickups; transcription turntables; automatic record combinations; accessories.

Ronette-Holland
135 Front Street, New York 5, N. Y.
Crystal cartridges; pickup arms; microphones; crystal tweeters.

Sanford Electronics Corp.
157 Chambers St., New York 7, N. Y.
Distributors: audio equipment.

Hermon Hosmer Scott, Inc.
385 Putnam Ave., Cambridge 39, Mass.
Amplifiers; equalizer-preamplifiers; noise suppressors; tuners; turntables; variable speaker crossovers; sound-level meters and analyzers; acoustic instrumentation.

Siemens & Halske Manufacturing
Black Oak Ridge Road, Wayne, N. J.
Imported radios, phonographs; single packaged AM-FM short-wave tuners with audio amplifiers and speakers.

Sightmaster Corp.
111 Cedar St., New Rochelle, N. Y.
Amplifiers; speaker systems; record changers; AM-FM tuners; cabinets; components.

Mark Simpson Mfg. Co., Inc.
32-28 49th St., Long Island City 3, N. Y.
Amplifiers; public address amplifiers; tape recorders; disc recorders; intercommunication systems.

Sonex, Inc.
245 Sansom St., Upper Darby, Penna.
Amplifiers; preamplifiers.

Sonotone Corp.
P.O. Box 200 Elmsford, N. Y.
Ceramic phonograph cartridges.

Spectrutone Sound Associates, Inc.
66 E. Gloucester Pike, Barrington, N. J.
Phonograph records.

Stan White, Inc.
Division of Eddie Bracken Enterprises
725 S. La Salle St., Chicago 5, Ill.
Amplifiers; loudspeakers.

Standard Wood Products Corp.
47 W. 63rd St., New York 23, N. Y.
Speaker enclosures; cabinets for radio-phonographs and television-radio-phonograph combinations.

Stephens Manufacturing Corp.
8538 Warner Drive, Culver City, Calif.
Loudspeakers and enclosures; amplifiers; condenser microphones; wireless microphone; multicellular horns; high-frequency drivers; theatre loudspeakers.

Stromberg-Carlson Company
1225 Clifford Ave., Rochester 21, N. Y.
Audio components and completed units in matching cabinets.

Tannoy (America) Limited
in association with
Tannoy (Canada) Limited
36 Wellington St. East, Toronto 1, Ontario, Canada
Loudspeakers; enclosures; preamplifiers; amplifiers; pickup cartridges.

Tech Laboratories, Inc.
Bergen & Edsall Blvds., Palisades Park, N. J.
Reverberation generators; attenuators; switches; potentiometers; decade boxes; bridges; test equipment.

Technical Tape Corp.
177th St. & Ft. Harlem River, Bronx 53, N. Y.
Recording tape and allied products.

Telectrosonic Corp.
35-18 37th St., Long Island City 1, N. Y.
Tape recorders; flutter bridges; transformers.

The Tetrad Company, Inc.
62 Saint Mary St., Yonkers 2, N. Y.
Diamond phonograph styli.

Thorens Company
New Hyde Park, N. Y.
Record changers; automatic and manual record players; transcription turntables.

Tung-Sol Electric Inc.
95 Eighth Ave., Newark 4, N. J.
Vacuum tubes for audio.

Ultra Hi-Fi Company
709 Sip St., Union City, N. J.
Sound systems; cabinets; speaker enclosures.

United Audio Products
Division of United Optical Mfg. Corp.
202-4 E. 19th St., New York 3, N. Y.
Loudspeakers; tweeters; woofers, coaxial speakers.

United Transformer Co.
150 Varick St., New York 13, N. Y.
Amplifier kits; transformers; filters; reactors; toroids.

University Loudspeakers
80 S. Kensico Ave., White Plains, N. Y.
Loudspeakers; loudspeaker systems; enclosures; dividing networks.

V-M Corporation
Benton Harbor, Michigan
Tape recorders; phonographs; record changers.

J. C. Warren Corp.
21 Hanse Ave., Freeport, N. Y.
Tape recorders; memory units and other magnetic recording and playback equipment for special applications; transmitters and receivers. Development work.

Weathers Industries, Inc.
66 E. Gloucester Pike, Barrington, N. J.
FM phonograph pickups; FM manual and automatic record players; records.

Webster-Chicago Corporation
5610 W. Bloomingdale Ave., Chicago, Ill.
Phonographs; tape recorders; radio-phonographs; clock radios.

Westminster Recording Co., Inc.
275 Seventh Ave., New York 1, N. Y.
Phonograph records.

Zenith Radio Corp. of New York
527 W. 34th St., New York 1, N. Y.
Radios; television sets; phonographs; combinations.

The Audio Fair
67 W. 44th St., New York 36, N. Y.
Business management of the Audio Fair.

Japanese Audio Fair

The Japanese people's traditional love of music and the inquiring mind of their engineers have resulted in a Japanese hi-fi industry that is showing remarkable growth.

The first formal gathering of hi-fi enthusiasts occurred during the occupation period, in 1951. Since then, a Japanese section of the AES has been formed and officially chartered by the parent society (January, 1954, issue of the JOURNAL, **2**, No. 1, p. 60) and three audio fairs have been staged.

The most recent Fair was held in Tokyo in December, 1954. Actual attendance was listed at 58,000 with 49 manufacturers participating.

The Tokyo Fair was spread out over three different locations: These were the Matsuya Department Store, where the various manufacturers displayed their products and audio components; the Kokusai Radio Center, where demonstrations were given; and the Asahi Building Auditorium, where technical papers were presented.

A stereophonic demonstration was presented, using components furnished by the Fuji Sound Company of Tokyo. The technical aspects of stereophonic sound were explained by John Nakamura, Chairman of the Japanese Section of the AES.

Ten manufacturers of soundproofing materials provided a special listening room in the Matsuya Department Store. With this arrangement, it was not necessary to operate loudspeakers at each exhibit—an excellent idea!

Three of the standard single-channel broadcasting stations in Tokyo joined together to provide a stereophonic broadcast in which members of the general public could participate by simultaneously using three regular receiving sets in their homes.

At the technical session, Kenzo Nakajima delivered the opening address.

The following technical papers were presented:

"DISC RECORDING" by Shozaburo Wada.
"LOUDSPEAKER DESIGN" by Masao Nishimaki.
"AMPLIFIER DESIGN" by Yuro Otobe.
"HIGH FIDELITY COMPONENTS" by Yoshikazu Tomita.
"LOUDSPEAKER SYSTEMS" by Tsuyoshi Ito.

(Unfortunately, abstracts of these papers were not available at press time. They will be published as soon as received.—*The Editors.*)

In addition to the annual Audio Fair held in Tokyo, it is planned to hold fairs this year in both Kobe and Osaka. With several hundred manufacturers of audio components now active in Japan, and with the tremendous interest shown by the Japanese public, there can be no doubt concerning the successful future of hi-fi in Japan.—WARREN BIRKENHEAD.

Section Meetings

COLUMBUS

Chairman: J. E. Anderson
Secretary: William E. Parker, 1271 Republic Ave., Columbus, Ohio
Paper: "Construction and Installation of Pipe Organs," A. W. Brandt, November 23, 1954.

LOS ANGELES

Chairman: Herbert E. Farmer
Secretary: Daniel H. Weigand, 3122 W. 152 Place, Gardena, Calif.
Papers: "Speech Input and Mixing Consoles," Charles Broneer and Gordon Edwards, Cinema Engineering Co., December 28, 1954.
"Stereophonic Sound System at the Hollywood Bowl," Oliver Berliner, Oberline, Inc., and Walter A. Midcalf, Otto K. Olsen, Inc., January 25, 1955.

NEW YORK

Paper: "Examination and Appraisal of Stereophonic Recording and Reproduction versus Directional Sound Recording and Reproduction," C. Robert Fine, Fine Sound, Inc., January 18, 1955.

SAN FRANCISCO

Chairman: William J. Rolly
Secretary: Robert C. Acker, 1434 Grizzly Peak Blvd., Berkeley 8, Calif.
Paper: "A Review of Literature on Psychoacoustics," Ross H. Snyder, Ampex Corporation, January 10, 1955.

Los Angeles Section Elects Officers

The Los Angeles Section held its annual election meeting on January 25, 1955. The following officers were elected:

Chairman: Sidney Alder
Vice-Chairman: O. L. Dupy
Secretary: Fritz Held
Treasurer: Tom Gibbons

Letters

(Note: Comments by readers on the letters below are welcomed.)

Record Speeds

I have an interesting historical problem, and I hope that some of your readers may be able to help me. What is the origin of the magic numbers 78 and 33⅓ (especially the ⅓)?

SIDNEY V. SOANES
64 Airdrie Road
Toronto 17, Ontario.

Audio Fair Comment

The R.P.I. Chapter has followed with keen interest the progress of the AES-sponsored New York Audio Fair held annually in conjunction with the AES Convention in the Hotel New Yorker. We have looked to the Audio Fair for the display of sound reproduction equipment and accessories with emphasis on those of technical excellence. Our student members have sought intelligent comments and suggestions from competent professionals in attendance and have in the past, come away from the Fair full of enthusiasm for Audio Engineering. This year we noticed a decided and definite decrease in the professional aspects of the exhibits.

As has been its custom, the R.P.I. Chapter devoted a full meeting, immediately after the October '54 Audiorama, to an open discussion of equipment highlights. It was quickly noted by the ten attendees, officers included, that in all 3.5 floors of the Fair, only two or three exhibits even pretended to attract professional interest, and even these were frequently, if not always, manned by technically uninformed salespeople. The few noted manufacturers of professional equipment in attendance concentrated heavily on their consumer lines. The Audio Fair has gone completely to the consumers!

This Chapter respectfully suggests that sponsorship by the Society of a strictly consumer event, to the exclusion of all others, is incongruous and short-sighted. Further to continue the trend of the past two Fairs, especially the last, will drive away the very professionals whom the AES may wish to attract to its Convention, and the Society will thus defeat its own purposes.

Recognizing the reputation and drawing power of the Audio Fair, as well as the monetary gain of sponsorship, we suggest that a portion of the exhibits be devoted exclusively to professional demonstrations and that manufacturers be encouraged to provide competent engineers to discuss their product with other interested professionals and students. We further suggest that this area of the Fair be reserved to technically minded persons by limiting attendance to AES members and their guests, identified appropriately, with the cognomen "guests" so interpreted as not to exclude genuinely interested persons. An admission charge, such as used for Convention papers in the past, might be employed as another limiting measure.

The Rensselaer Chapter unanimously urges action on the part of the National Society, either as suggested or with modifications, so that this nonprofessional trend may be checked and reversed.

JOHN D. MCKENDREE, Secretary
R.P.I. Chapter of the AES
Rensselaer Polytechnic Institute
Troy, New York

Reply by the President of the AES

Mr. McKendree's point is well taken and it is of serious concern to all the officers of the Society and the Fair Management. A goodly number of hours was expended by the Board of Governors of the Society during the year 1954 searching for the answer.

Basically, the problem is this, from the exhibitor's viewpoint: He exhibits for one reason—to show his equipment to the purchasing public. An analysis of the people who attend the Fair indicates that about eighty percent are not engineers, nor are they technically trained. They are the typically hi-fi fans, musicians, and persons just interested in seeing the show.

The exhibitor, knowing this, does not see the value of keeping members of his technical staff—who are expensive men and not used to dealing with the purchasing public—on hand to demonstrate his equipment. Rather, he has his sales engineer on duty; the latter may or may not know all the technical answers but is well versed in dealing with the prospective purchaser, which is of greater immediate importance to the exhibitor.

The solution to the problem is not an easy one. We have under consideration for this coming year a plan to set aside one day for the engineer and other technically trained people. On that day, each exhibitor would be requested to have his best technical men available for discussion and demonstration.

This idea, if it can be carried out, although it is not the solution to the problem of raising the over-all standard of the Fair, will permit the engineer to have his day with the knowledge that competent men will be available to answer his questions.

A. A. PULLEY, President
Audio Engineering Society
P.O. Box 12, Old Chelsea Station
New York 11, New York.

AES Employment Register

The AES Employment Register Committee welcomes "Situations Wanted" and "Positions Available" notices. There is no charge to members of the AES. All replies and other correspondence should be directed to:

Mr. E. V. B. Kettleman, Chairman
Employment Register Committee
Audio Engineering Society
P.O. Box 12, Old Chelsea Station
New York 11, New York.

Situations Wanted

Audio Research Engineer. Fifteen years' experience in microphone development, five years' experience in the physics of precious metals. Desires appropriate position in metropolitan New York or elsewhere. Send reply to Mr. E. V. B. Kettleman at the above address.

Audio or Sales Engineer. Eight years as salesman. Graduate of RCA Institutes, licensed New York State electronics instructor. Amplifier, equalizer, and recording experience. Available for immediate placement. Send reply to Mr. E. V. B. Kettleman at the above address.

Audio Technician. Wide experience with high-quality audio amplifiers and reproducing systems. Home study course in audio engineering. Available for manufacturing or recording work in Metropolitan New York. Send reply to Mr. E. V. B. Kettleman at above address.

Membership Information

New Members

Honorary Member

Black, Harold S., Bell Telephone Laboratories, Inc., Murray Hill, N. J.

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Change of Grade

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Urban, Charles, 44 Greenwood Drive, Millburn, N. J.
Wilson, Norman E., 225 N. 18th St., East Orange, N. J.

Deceased Member

It is with sincere regret that the Society notes the death of John E. Crockett who lived at 3770 Cardiff, Los Angeles 34, Calif.

Journal Authors

BENJAMIN B. BAUER's biography appears on page 51 of this issue.

ABRAHAM B. COHEN's biography appears in the July, 1954 issue of the JOURNAL (2, No. 2, p 201).

MURLAN S. CORRINGTON

MURLAN S. CORRINGTON was born on May 26, 1913, in Bristol, South Dakota. He received his B.S. degree in electrical engineering in 1934 from the South Dakota School of Mines and Technology and his M.S. degree in 1936 from Ohio State University. From 1935 to 1937, he was a graduate assistant in the physics department of Ohio State University. In 1937 he joined the Rochester Institute of Technology, where he taught mathematics, mechanics, and related subjects. Since 1942, Mr. Corrington has worked in the advanced development section of the RCA-Victor Television Division, Radio Corporation of America, at Camden, New Jersey. He is manager of audio, acoustics, and antennas for the aforementioned section.

Mr. Corrington is a member of Sigma Pi Sigma, the Acoustical Society of America, the Society for Industrial and Applied Mathematics, and a Fellow of the IRE. He holds several offices in the IRE; he is vice-chairman of the Sound Recording and Reproducing Committee, Chairman of the Basic Measurements Subcommittee of the Radio Frequency Interference Committee, and Vice-Chairman of the national Professional Group on Audio.

The author of two textbooks, Mr. Corrington has also written technical papers on circuit theory, frequency modulation, transients and cone motion in loudspeakers, and also on distortion in phonograph records. He holds seven U. S. patents.

LEE GUNTER, JR., was born on February 28, 1920. From 1938 to 1940, he attended Blackburn College, Carlinville, Illinois; and from 1940 to 1942 he attended Westminster College, New Wilmington, Pennsylvania, where he received his B.S. degree in mathematics. During the summer of 1942, Mr. Gunter studied advanced acoustics at Brown University, Providence, Rhode Island.

LEE GUNTER, JR.

Mr. Gunter spent the years 1942 to 1945 in the field of audio electronic engineering at the Eatontown Signal Laboratory, Fort Monmouth, New Jersey, and the Radio and Radar Laboratories, Wright Field, Ohio. He joined Shure Brothers, Inc., Chicago, Illinois, in 1945, and for the past several years he has been head of the phonograph reproduction section of their development department. Mr. Gunter has done development work on a variety of electroacoustic devices, including directional microphones, phonograph pickups, and magnetic recording heads, having contributed numerous inventions in these fields.

Mr. Gunter is a member of the Acoustical Society of America and secretary of the Chicago Acoustical and Audio Group.

FREDERICK V. HUNT's biography appears on page 49 of this issue.

A. M. MAX

ABRAHAM M. MAX was born in Sheboygan, Wisconsin. Attending the University of Wisconsin, he received a Ph.D. in 1937 in chemical engineering with minors in physics and physical chemistry. From 1937 to 1941, Mr. Max was a chemist with the Fernstedt Division of General Motors Corporation in Detroit, working primarily on decorative plating development on automotive hardware. From 1941 to 1944, he was assistant professor of chemical engineering at the University of North Dakota. Since 1944, Mr. Max has been with the Engineering and Development Section of the RCA Victor Record Division in Indianapolis. Until 1950, he was supervisor of the Metallizing and Plating Group, which in 1948 was awarded

the RCA Award of Merit for the development of matrix processing methods which contributed to materially improved record quality. Since 1950, Mr. Max has been manager of the Chemical and Physical Laboratory. He is a member of the ACS, the Electrochemical Society, and the American Electroplaters Society.

FRANK RADOCY was born in 1921 in Stamford, Connecticut. In 1939, he was employed by Audio Devices, Inc. as a laboratory technician and has been with that company ever since, with the exception of four years in the U. S. Army Air Force during World War II. He spent three years attending special evening courses in electronics and radio at the Wright Technical and Bridgeport Engineering Institutes. In 1946, Mr. Radocy was appointed manager of the lacquer department. In 1949, he was appointed to his present position as director of quality control. His main interests lie in the testing and development of magnetic tapes and lacquer recording disks.

CHARLES ERNEST SEELER

CHARLES ERNEST SEELER was born on April 8, 1920. He studied at the Institute of Technology in Berlin from 1939 to 1940, the Institute of Technology of Darmstadt from 1940 to 1944, and received his B.S. degree in 1942 and his M.S. degree in physics in 1944.

Before joining Shure Brothers, Inc., he worked at the Ringsdorff Werke in Germany, the University of Notre Dame, and Electro-Voice, Inc. Mr. Seeler joined Shure Brothers, Inc., in 1953, in a research and development capacity, specializing in phonograph reproduction.

ROBERT A. VON BEHREN

ROBERT A. VON BEHREN was born in Chicago, Illinois, in 1921. He received a B.S. degree in electrical engineering from Purdue University in 1943. From 1943 to 1946 he was employed by the Sperry Gyroscope Company as field service engineer in airborne radar and navigation aids. He joined the Indiana Steel Products Company in 1946 as research engineer and was active in the development of magnetic recording tape and recording heads. Since 1948 Mr. von Behren has been associated with the Minnesota Mining & Manufacturing Company where he has been active in magnetic tape research and development and is at present assistant technical director of the Magnetic Products Division. He is a member of IRE Committee 19 on recording and reproducing standards, a member of the standards committee of the Magnetic Recording Industry Association, and a member of Tau Beta Pi and Eta Kappa Nu.

R. J. YOUNGQUIST

R. J. YOUNGQUIST was born in St. Paul, Minnesota, in 1926. After spending two years in the Navy, from 1944 to 1946, he received a B.S. degree in electrical engineering from the University of Minnesota in 1948. In 1952 Mr. Youngquist received his M.S. degree in electrical engineering from the University of Minnesota. He joined Minnesota Mining & Manufacturing Company in 1950, working on magnetic recording methods and magnetic tape. Mr. Youngquist is a member of the IRE.

ACKNOWLEDGMENT

For detail work and other valuable assistance in the editing and production of the JOURNAL, the Managing Editor gratefully thanks Osmond K. Kendall, William H. Offenhauser, Jr., and Robert Winston.

Information for Convention and/or JOURNAL Authors

SUGGESTIONS FOR PREPARING MANUSCRIPTS, PHOTOGRAPHS, CHARTS, DRAWINGS, AND LANTERN SLIDES; LETTERING SIZES, MAILING INSTRUCTIONS, ETC.*

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Please do not send black-and-white lantern slides or color transparencies for publication—only photographic prints or original drawings should be submitted.

Lettering. On the aforementioned 8½ in. x 11 in. sheets, lettering and numerical data should not be less than 0.12 in. high. Necessary labeling should be lettered onto curves and sketches. On the other hand, if extensive descriptive material is needed, it is better to put such information into the typewritten captions rather than to attempt to letter the information onto the curve or sketch.

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Mail that copy of the manuscript which is accompanied by the illustrative material (the Managing Editor's copy) *flat,* with plenty of stiff cardboard enclosed. It is advisable to mark the envelope "PLEASE DO NOT BEND."

ORAL PRESENTATION OF THE PAPER

Time allotment. The average time allowed for any paper, unless the author requests more time on his Author's Form, is 20 minutes.

The paper should be presented by the author, if possible. If you are not going to deliver your paper in person, please supply the name of your alternate to the Convention Chairman as early as possible.

Special oral version. An informal version of approximately 20 minutes, having an air of spontaneity, is usually more effective than a rushed verbatim reading of the manuscript exactly as written for publication. Many authors, after submitting the formal full-length version of their paper for publication, prepare an *informal* version for their guidance during oral delivery.

Demonstrations. Demonstrations always add interest. They should be set up well in advance of the particular session for which they are intended and tested under actual operating conditions. The Convention Committee will cooperate in every way within its power.

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Lantern slides. Photographs, diagrams, charts, and curves intended to accompany oral delivery should be in the form of standard American lantern slides (3¼ in. x 4 in.) or 2 in. x 2 in. transparencies. The long dimension of the projected area should be horizontal in the standard slide, but may be either horizontal or vertical in the 2 in. x 2 in. slide.

PLEASE NOTE: Opaque projection of paper prints or drawings is not recommended. Nor can we guarantee that facilities for this type of projection will be provided. Because of the dimness of the image, opaque projection is unsatisfactory for large audiences.

Lettering on lantern slides. Charts, diagrams and curves from which lantern slides are to be made should be held within the proportions or overall dimensions of 7 in. x 10 in., with no more than 20, and preferably only 15 words to a chart. Vertical Gothic capitals are recommended.

For a 7 in. x 10 in. working area, the smallest desirable letter height is 0.14 in. (made with a Leroy pen 0 or Wrico pen 7).

Recommended, too, are the following line widths:

For curves—1½ to 2 points or 0.021 in. to 0.028 in.
For grid rules—½ point or 0.007 in.
For reference lines—1 point or 0.014 in.

Thumb marks. To indicate proper orientation, a thumb mark should be placed in the lower left-hand corner of the slide, when the latter is viewed as it will appear projected on the screen.

More complete information on lantern slide dimensions is given in American Standard Dimensions for Lantern Slides, Z38.7.19-1950.

CONVENTION COMMITTEE, AES
PUBLICATIONS COMMITTEE, AES

* The suggestions offered herein have been borrowed in part from the Society of Motion Picture and Television Engineers, the Acoustical Society of America, and the American Standards Association.

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